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Heat Stress Effects of a Navy/USMC vs. Army Aviator Ensemble in a UH-60 Helicopter Simulator

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This aviator heat stress study used a between test subjects design with one environmental condition (hot) and two current (U.S. Navy/U.S. Marine Corps vs. U.S. Army) rotary-wing MOPP4 ensembles encumbered with additional ballistic protective and overwater survival components. Four U.S. Marine Corps (USMC) aviators (2 UH-60 crews) were tested in the hot condition and their physiological, subjective, and flight performance responses compared to those of 14 Army aviators (9 crews) who tested in the same condition in a previous related study. The environmental condition consisted of 100°F (dry bulb) and 20 percent relative humidity (RH) in an environmental chamber where test subjects walked on a treadmill for 20 minutes to simulate preflight outdoor activities, and 100°F and 50 percent RH (90°F wet-bulb globe temperature [WBGT]) in the UH-60 simulator. Every 30 minutes the right seat pilot encountered instrument meteorological conditions and ascended to 2000 feet to perform a 10-minute set of standard maneuvers. These maneuvers included straight and level (SL), right standard rate turn (RSRT), left climbing turn (LCT), and left descending turn (LDT). After each iteration of the set of standard maneuvers, the pilot returned to nap-of-the-earth (NOE) and contour flight between control (Contined)

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points. The right seat pilot also performed up to four 1-minute hovers (HOVs) and hover turns (HOVTs) in the first 2-hour sortie and three in the second 2-hour sortie. The simulator's data acquisition system captured relevant combinations of airspeed, altitude, turn and climb rates, trim, and roll for each type of flight maneuver. Mean crew endurance in the hot condition for the Navy/USMC and Army protective aviator ensembles were 132 and 98 minutes, respectively. Although mean core temperature profiles for the two ensembles were not substantially different, heart rates were lower for the group wearing the Navy/USMC ensemble. In the hot condition, the average sweat rate for the aviators in the Navy/USMC protective ensemble was substantially lower (1033 cc/hr) than for the equivalent Army ensemble (1494 cc/hr). The Navy/USMC ensemble allowed a greater percentage of sweat evaporation (52 +/- 2.6 percent SE) than the Army ensemble (27 +/- 3.2 percent). Conversely, the percentage of sweat retained in the uniform was greater for the Army (73 +/- 3.2 percent) than the Navy/USMC (48 +/- 2.6 percent) ensemble. Average composite flight performance scores did not differ substantially across the two ensembles. Likewise, there were no significant differences in mean number of dangerous flight incidents (e.g. controlled flight into terrain [CFIT], tail rotor strikes, etc.). Although the small number of test subjects in each group precluded definitive statistical conclusions, the results suggest that the Navy/USMC MOPP4 protective ensemble is associated with lower heat strain, primarily due to less sweat retention that allowed more evaporative cooling.

Acknowledgments

We extend our sincere appreciation to the courageous, professional, and forbearing United States Marine Corps (USMC) aviators who volunteered for this demanding study. Working with them was most enjoyable. We would also like to acknowledge the many support personnel who contributed to the successful completion of this study. Art Estrada, Hughes Technical Services Company, served as the primary UH-60 simulator operator with CPT Peter Mack assisting as backup operator. SGT Roger Jones assisted with test subject preparation and recovery. Hughes Technical Support Services personnel graciously worked overtime to put the simulator and its environmental control systems on line after a storm-related electrical surge knocked out the computer cooling systems. The very talented and experienced Mr. Alan Lewis, United States Army Aeromedical Research Laboratory's (USAARL's) biomedical engineer, and Mr. Robert Dillard, electronics technician, tested and calibrated the simulator's data acquisition system. Dr. Heber Jones and Mr. Andy Higdon set up the database files and software for the simulator's "HAWK" data acquisition systems and assisted with cross-platform data access. Lastly, our thanks to LTC Malcolm Braithwaite, MD, Royal Army Medical Corps (RAMC), for support as the study's medical monitor.

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Introduction

This study was implemented to compare physiological, psychological, and flight performance effects of heat stress exposure for aviators wearing current U.S. Navy/U.S. Marine Corps (USMC) versus U.S. Army rotary-wing encumbered chemical defense level-4 mission oriented protective posture (MOPP4) ensembles. The evaluation was performed at the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, during June 1997 for the Air Warrior (AW) project manager operating under the program manager (PM), U.S. Army Aircrew Integrated Systems (ACIS). Funding was provided by the U.S. Navy Air Systems Command, and volunteer test subjects were from the USMC. The objective of this study was to provide data to the AW/ACIS PM regarding the differences (advantages/disadvantages) in mission endurance, flight performance, and physiological and psychological heat stress responses between the Navy/USMC vs. Army MOPP4 aviator uniforms.

The AW project is a joint Army, Navy, and USMC long-range research and development effort for incremental development of state-of-the-art rotary-wing combat-capable aircrew ensembles using integrated soldier-system design methods. The primary goal is to enhance aviator effectiveness and survivability when conducting military operations across conditions spanning the entire spectrum of mission and environment-related performance and survivability risks. Proposed new-generation aviator ensembles will be developed by industry to meet AW design goals of modularity, mission configurablility, chemical agent protection, and integrated advanced life support and ballistic protection components (ATCOM, 1995).

Background

Environmental and mission-related heat stress factors

Aviators are often exposed to substantial heat stress when performing outdoor preflight duties and flying unair-conditioned transport helicopters in hot weather environments. The environmental components of heat stress include elevated ambient temperature, humidity, wind speed, and radiant heat load. These separate heat stress components can be succinctly expressed as a single indicator, or thermal stress index, such as the wet-bulb globe temperature (WBGT) used by the U.S. military. Mission factors that often accelerate effects of environmental heat stress include the wearing of occlusive protective ensembles overlaid with multiple layers of personal aviator protective and survival gear (resulting in reduced heat dissipation and sweat evaporation), sustained operational tempos that reduce physiological and behavioral thermoregulatory capabilities due to fatigue and persistently elevated metabolic rates, and aircraft configurations (e.g., doors closed) which favor heat retention in crew compartments. Individual factors such as illness, fever, medications, and dehydration can also significantly reduce thermoregulatory reserve or accelerate the onset and progression of heat strain, thereby increasing the likelihood of performance decrements; failure to complete designated missions; and occurrence of overt heat illness.

Numerous field studies have convincingly demonstrated that significantly elevated temperatures can easily occur in helicopter cockpits during hot weather conditions. Breckenridge and Levell (1970), for example, found that WBGT readings in the closed cockpit of a parked AH-1G attack helicopter fully exposed to summertime solar radiation were frequently greater than 104°F and dry-bulb air temperatures up to 132°F. Froom, et al. (1991) demonstrated that, 1 hour after moving into full sunlight, cockpit WBGT in a Bell 212 helicopter became 13°F (7.2°C) greater than ambient WBGT. Likewise, Thornton and Guardiani (1992) showed that summertime WBGT in the closed cockpit of a hovering UH-60 transport helicopter was approximately 9°F (5°C) higher than at nearby airfields.

High cockpit and cabin temperatures occur because of heat transfer into crew compartments from hot external environments, as well as endogenous heat sources from the aircraft itself, such as engines, auxiliary power units, and electronic systems. The greenhouse effect then exacerbates heat stress by trapping heat in a relatively small and poorly ventilated crew compartment.

The greenhouse effect occurs in enclosures having windows that transmit a high percentage of visible-band solar energy, but are relatively opaque to the longer wavelength infrared (IR) radiation emitted from interior surfaces and crewmembers. Additionally, elevated humidity and carbon dioxide levels in a crew compartment facilitates absorption of radiated and transmitted IR energy by cabin air. The increased temperatures due to IR energy trapped by the air in an aircraft cabin along with the primary heat stress effects of increased humidity from respiration and evaporating sweat can significantly increase the cockpit WBGT index.

Physiological heat stress responses and chemical defense (CD) ensembles

Physiologically, when endogenous or exogenous factors cause net heat storage within body tissue compartments, core temperature increases and protective compensatory heat dissipating processes are progressively activated (Epstein et al., 1987). Primary thermoregulatory processes include sweating, peripheral vasodilation, increased cardiac output, and shunting of blood flow from central visceral organs to the skin. Other heat stress responses, such as elaboration of protective heat shock proteins, are only discernable at cellular and biochemical levels.

The metabolic rate for routine flight maneuvers in military helicopters is in the range of 100-200 watts, which can be classified as light physical work (e.g., Thornton et al., 1984). Therefore, the contribution of metabolic thermogenesis to rise in core temperature during routine flight will usually be relatively minor. However, if cockpit conditions are sufficiently hot, the combination of passive and even slight metabolic heat gains can cause aviator core temperature to progressively increase to levels that impair performance and cause heat illness.

Within the U.S. Army, the acronym "MOPP" is used with a numerical suffix (0-4) to signify five standard levels of mission oriented personal protection against chemical and biological (CB) threats. Unit commanders designate appropriate MOPP levels for their units based on estimates of the nature and immediacy of CB threats. Although MOPP ensembles vary somewhat across the services, typical MOPP components include a chemical agent absorbent over- or under-garment, CB protective mask and impermeable hood, and butyl rubber protective gloves and boots. These components are worn simultaneously to provide level four MOPP (MOPP4) CB protection. Although there has been a continuous improvement in the design in the biophysical properties of MOPP4 components, complete MOPP4 ensembles still remain bulky and encumbering, thereby significantly impairing thermoregulation as well as psychomotor performance.

CD personal protective components and overgarments contribute to heat stress because they significantly impair thermoregulation due to high total insulation values and low water vapor permeability (Gonzalez, 1988). Their high thermal resistance significantly restricts the rate at which endogenous heat can be transferred across the thickness of the various components layers.

Low water vapor permeability for CD ensembles signifies reduced maximum rates of evaporative skin cooling. When ambient temperatures exceed body temperature, sweat evaporation is the only effective method of dissipating body heat (Sawka and Wenger, 1988). Complete evaporation of 1 liter of sweat provides 580 kcal of surface cooling. However, effective sweat evaporation rates, as determined by the rate of evaporation of sweat through the outer surface of a uniform, determines the evaporative cooling power available to the individual. It is apparent, therefore, that actual and effective sweating rates may differ considerably.

In heat stress conditions, low water vapor permeability causes the air layer between the skin and inner surface of a CD ensemble to become rapidly saturated with sweat vapor. As this occurs, the net evaporation of sweat decreases and may approach zero. Vigorous sweating, however, typically continues. The unevaporated sweat is then either absorbed and retained in the flight uniform and CD overgarment, or accumulates in dependent parts such as boots, gloves, and CD mask. Since this unevaporated sweat cannot be used for cooling, it only contributes, in a deleterious manner, to dehydration.

Effects of heat stress and CB protective ensembles on performance

Most studies that have evaluated the effects of heat stress exposure on performance have typically used only relatively simple cognitive and perceptual tasks, time estimation, reaction time, tracking, and vigilance. Although the heat stress exposure threshold for performance decrements varies across individuals and types of tasks, studies consistently indicate that severe or lengthy heat stress exposures are associated with greater error rates and progressive performance decrements. Berglund et al. (1990), for example, developed a simple empirical model that showed a near-linear increase in Morse code decoding error rates for ambient temperatures above 26°C (78.8°F). Ramsey (1995) reviewed reports published between 1979 and 1991 on the effects of heat stress on performance. He found that complex psychomotor task performance levels become significantly decremented when ambient WBGT reaches or exceeds 30-33°C (86-91.4°F). Another review by Kobrick and Johnson (1992) showed heat stress related performance decrements occurring consistently across different studies for visual and auditory vigilance, marksmanship, pointer alignment, manual tracking, 5-choice task, and short-term memory. Hancock (1982) demonstrated that core (rectal) temperature increases of 0.4°F, 1.6°F, and 3.0°F were thresholds for onset of statistically significant decrements in dual task performance, tracking, and mental tasks, respectively. The hotter the ambient conditions, the sooner core temperature thresholds for onset of performance decrements were reached. Studies have also shown that the extent of heat stress-related reductions in performance are proportional to the degree of task complexity. Unfortunately, there is a paucity of data demonstrating significant associations between performance on simple types of laboratory tasks and more complex real-world tasks such as flying demanding sorties in modern helicopters.

Taylor and Orlansky (1993) published a comprehensive review of the effects of current MOPP4 ensembles on performance. CB masks, for example, typically impair vision, reduce auditory acuity, and degrade speech intelligibility. They also usually increase the work of breathing, alter normal respiratory patterns, and often elicit anxiety, clausterphobic reactions, and hyperventilation (Muza et al., 1995). Butyl-rubber MOPP gloves significantly increase completion times for manual dexterity tasks. A study by Lussier and Fallesen (1987) showed an 8 percent performance decrement on computer keyboard tasks when test subjects were in MOPP4. Task specific training performed while in MOPP4, however, has been shown to be at least partially efficacious in counteracting such performance decrements.

Methods and procedures

Study design

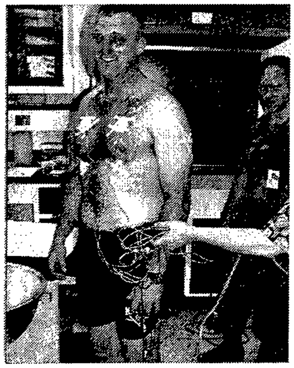
This study used a between test subjects design with one (hot) environmental condition and two different (Navy/USMC vs. Army) encumbered MOPP4 rotary-wing ensembles. Two independent groups of aviators were compared. Four USMC aviators (2 crews) were tested in the MOPP4-hot condition and their responses compared to those of the 14 Army aviators (9 crews) who tested in the same condition in a previous study described in Reardon, et al. (1996 and 1997).

Sequence of test session events

Prior to participation in the studies, all the aviator volunteers received a detailed briefing regarding the study and were informed of their right to withdraw at any time, at their discretion, without any penalties. The volunteer aviators read and signed an informed consent form approved by USAARL's human use review committee and were medically cleared for any evidence of disqualifying illness or excess cardiovascular, musculoskeletal, or other risks.

Test subjects arrived each day at approximately 0700, self-inserted a rectal thermistor, were assisted with the application of skin temperature sensors and electrocardiogram (ECG) leads, and then donned the designated uniform. Volunteers then entered USAARL's environmental chamber where they walked on treadmills at a 3 mph pace and 0 percent grade for 20 minutes (see figure 1). This method was used, per Thornton et al. (1992), to approximate the metabolic heat load generated during an actual UH-60 preflight inspection. After completing the 20-minute simulated preflight inspection, the crew walked a short distance to the USAARL UH-60 simulator. Core temperature and heart rate were monitored every 10 minutes to ensure adherence to physiological limits as approved in the research protocol (core temperature limit of 102.56°F, or 39.2°C, and heart rate not to exceed 90 percent of age adjusted predicted maximum). Pre- and

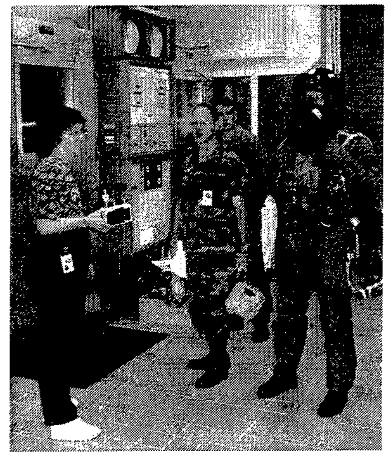
Test subject instrumentation & prep room → **Environmental chamber with 2 treadmills**



Instrumentation: core temp, heart rate sensors
Don flight uniform
Pre-test: nude and clothed weights
POMS questionnaire
Pre-test canteen weights
Initiate data recorders

Environmental chamber with 2 treadmills

Condition: 100°F, 20%rh

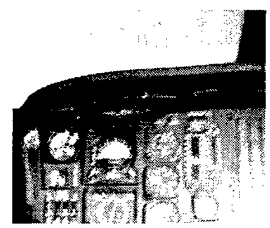


Simulated preflight:
20 minute walk on treadmill
3 mph, 0 grade
Pre-, & post preflight mood & symptoms questionnaire
Water ad libitum

UH-60 simulator

2 hrs: air assault scenario
10 min: simulated hot refuel break
2 hrs: medevac scenario

Condition: 100°F, 50%rh



Disconnect from portable data recorders
Assist test subjects into the cockpit
Connect to physiological data acquisition system
Technician initializes MATB for lift seat pilot
Sim operator initializes HAWK flight performance system
Every 30 mins: 10 min of set of standard maneuvers at 2-2.5Kalt
10 min med difficulty MATB
questionnaires: mood & symptoms
task load index (TLX)
Every 10 mins: manual data recording
core temp & heart rate
Cockpit environmental conditions

Monitoring station

Post simulator cool-down room

Post session clothed weight
Cooling: fans, iced towels
Hydration: cooled water
Post session POMS questionnaire

Remove sensors
Post test nude weight
Post test canteen weights
Final checks
Release for the day

Figure 1. Process for heat stress evaluation of Navy/USMC aviator ensemble.

posttest weights and fluid intake and output were obtained to determine sweating rates and levels of dehydration.

Each simulator flight session consisted of two 2-hour sorties (air assault (AA) and medical evacuation (MEDEVAC), respectively) with an intervening 10-minute simulated hot refueling break. Every 30 minutes during the simulator session, the right seat pilot encountered inadvertent instrument meteorological conditions (IMC) whereupon he commenced flying a 10-minute set of standard flight maneuvers. During the sorties, the data acquisition systems collected flight performance and physiological data. When subjective or objective indicators suggested that test subject tolerance limits were about to be reached, the volunteer pilots were instructed to make a simulated landing and then were assisted out of the simulator and escorted to a cooling and recovery room.

Environmental conditions

The pilots in this study tested only in the hot condition as described in Reardon et al. (1997). This consisted of 100°F (dry-bulb) and 20 percent relative humidity (RH) in the environmental chamber during the 20 minute simulated outdoor preflight activities, and 100°F and 50 percent RH (resulting in a WBGT of 90°F) in the UH-60 simulator. The WBGT value in the simulator included radiant energy emitted by three sets of heat lamps situated above each pilot's helmet. Lamp rheostats were set at 50 percent per Thornton et al. (1992).

Aviator ensembles

Annotated photographs of the U.S. Navy/USMC rotary-wing ensemble components tested in this study and the equivalent U.S. Army ensemble against which they were compared are provided in figures 2 and 3. The tested encumbered Navy/USMC MOPP4 aviator ensemble weighed 50.4 pounds vs. 57.1 pounds for the equivalent encumbered Army MOPP4 aviator ensemble (table 1). The Army CB battle dress overgarment (BDO) was 4.11 pounds (or 3.82 times) heavier than the Navy/USMC CB protective undergarment. The Army CB overgloves were 1.64 times heavier than the Navy/USMC gloves. Likewise, the Army CB mask with blower, filters, and battery weighed 4 pounds (or 1.8 times) more than the equivalent Navy/USMC system. The Navy/USMC combination of soft armor vest and hard armor chest plate was 13.25 pounds vs. 11.71 pounds for the Army hard armor chest plate. Likewise, the Navy/USMC AIRSAVE aviator survival vest with the integrated floatation collar was 1.1 pounds heavier than the combined weight of the Army survival vest, water wings, and wearable one person life raft.

USAARL's UH-60 research helicopter simulator

Capabilities and data acquisition

The current USAARL UH-60 research simulator was used to obtain flight performance measurements. Its hydraulic motion base provides 6 degrees freedom of motion allowing for acceleration cues in the lateral, longitudinal, vertical directions with pitch, roll, and yaw over a

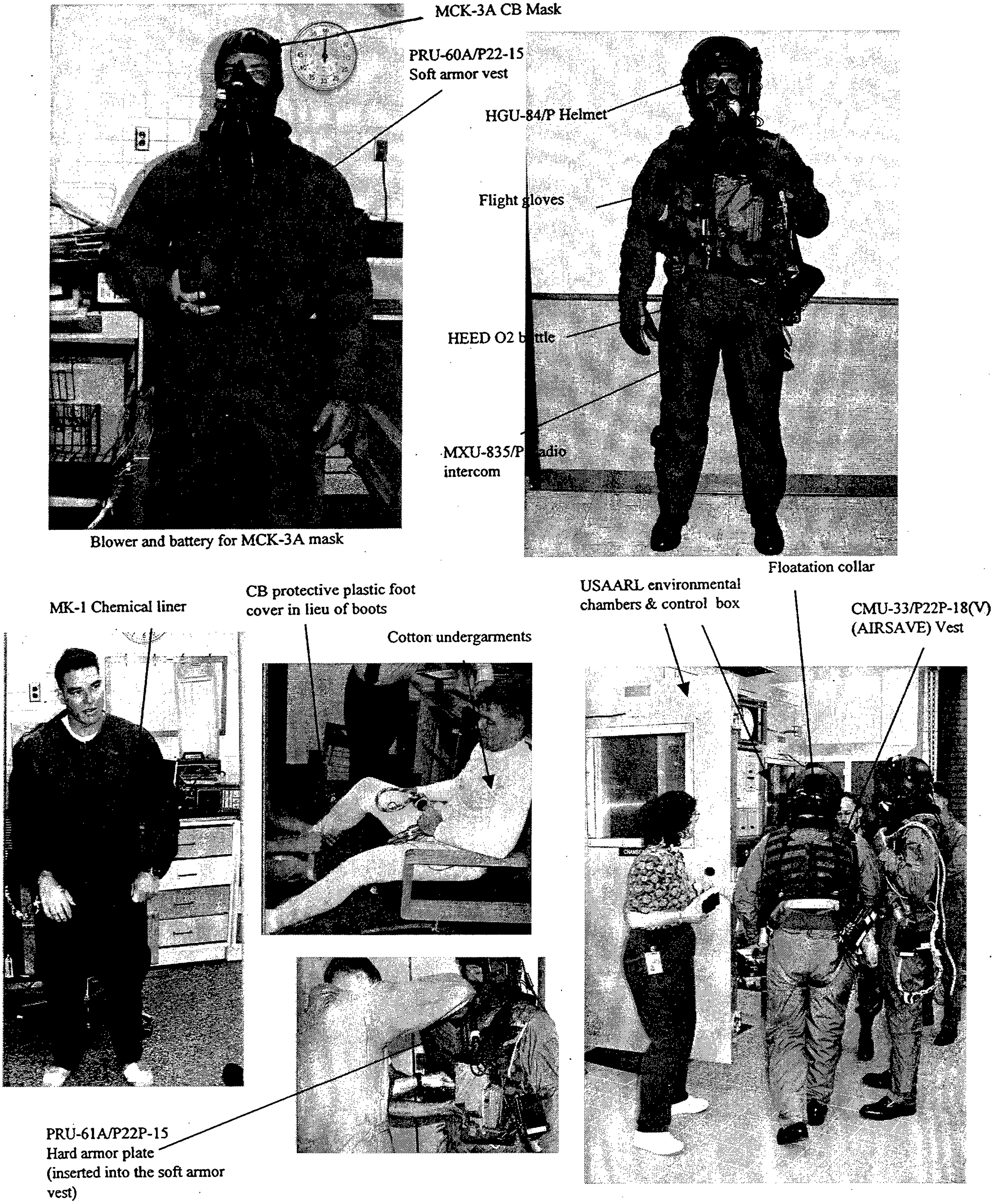


Figure 2. U.S. Navy/ USMC encumbered MOPP4 aviator ensemble.

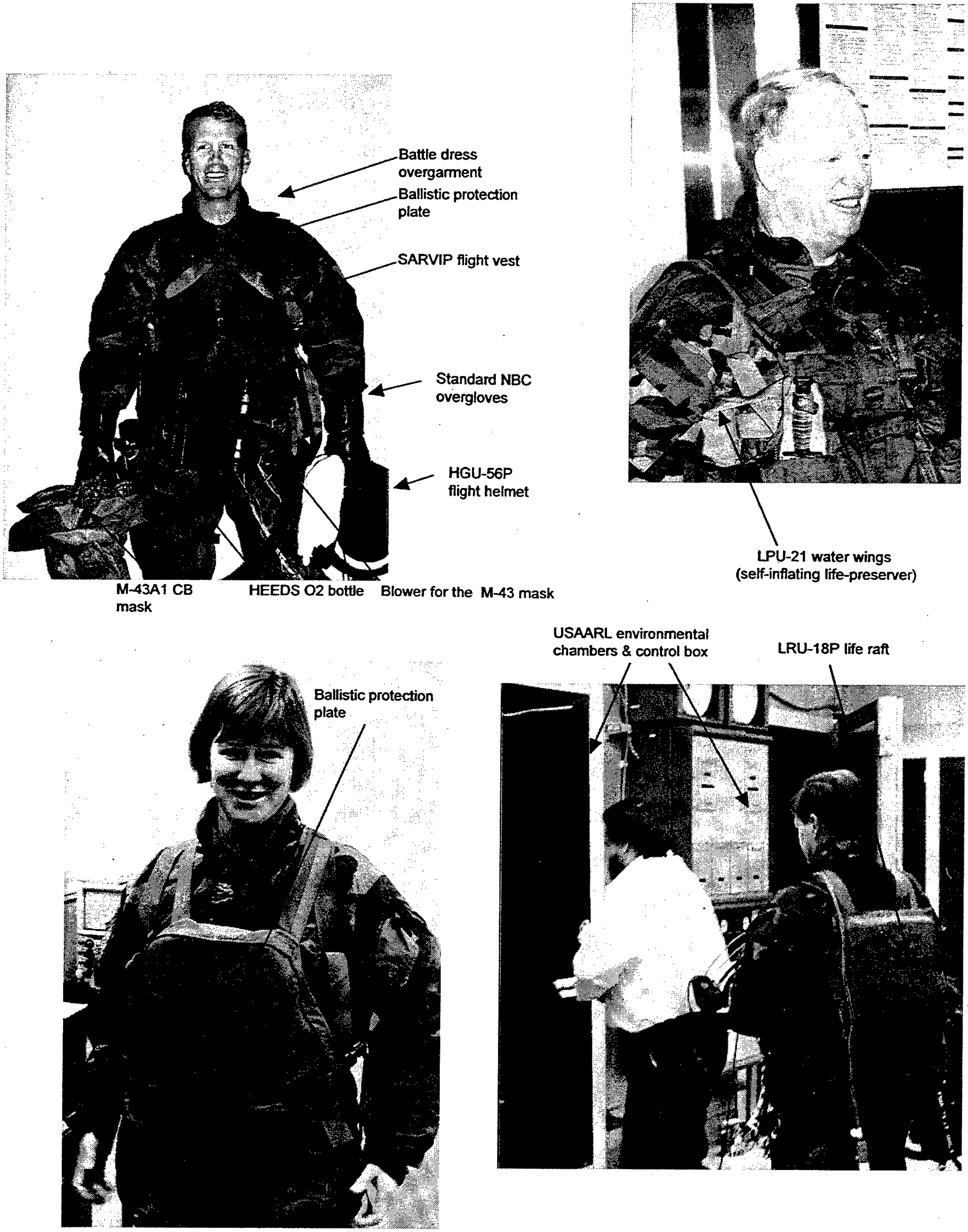


Figure 3. The U.S. Army encumbered MOPP4 aviator ensemble.

Table 1.

Aviator ensembles: Total and component weights.

Navy	kg	lb
Flight suit	0.92	2.04
MK-1 chemical liner	0.66	1.46
Combat boots	1.88	4.14
CB overgloves (7 mil)	0.06	0.14
Flight gloves	0.10	0.21
Cotton undergarments	0.36	0.79
MXU-835/P Radio intercom	0.55	1.23
PRU-60A/P22P-15 Soft armor vest	3.04	6.73
PRU-61A/P22P-15 Hard armor plate	2.94	6.52
*CMU-33 /P22P-18(V) (AIRSAVE) Vest	8.48	18.65
MCK-3A CB Mask (w/blower and battery)	2.33	5.13
HGU-84/P Helmet	1.52	3.36
MOPP4 fully encumbered average weight	**22.84**	**50.40**

* w/ Helicopter emergency egress device (HEED) O2 bottle and life preserver LPU-34/P

Army	kg	lb
ABDU	1.00	2.21
CB overgarments	2.52	5.57
Combat boots	1.81	3.99
CB overgloves (20 mil)	0.10	0.23
Flight gloves	0.08	0.19
CB overboots	1.43	3.16
LPU-21 a/P Water wings	1.39	3.06
LRU-18P life raft	2.16	4.76
Ballistic protection plate	5.31	11.71
*SARVIP	4.47	9.77
M43A1 CB Mask (w/blower, filters, and battery)	4.16	9.15
HGU-56P Helmet	1.51	3.32
MOPP4 fully encumbered average weight	**25.94**	**57.12**

* w/ Helicopter emergency egress device (HEED) O2 bottle

60 degree range. The simulator has a three-channel, four-window, digital image generator (DIG).

The UH-60 research simulator was equipped with an environmental control unit (ECU) that maintained specified target dry-bulb temperature and RH in the cockpit during the study. The ECU was capable of controlling cockpit conditions within a range of 68-105 °F (± 3 °F) and 50-90 percent RH (± 3 percent).

The flight instruments and controls in the UH-60 simulator were directly linked to a real-time data acquisition system controlled by a Digital Equipment Corporation (DEC) VAX 11/780 computer* . This 128 channel, automated data acquisition system continuously captured flight performance data at a 30 hertz (Hz) sampling rate (USAARL, 1991). The system continuously recorded cockpit instrument data such as airspeed, altitude, roll, pitch, and slip. Simulator flight data were stored on magnetic media linked to a DEC-VAX computer system. The data were then downloaded and analyzed with spreadsheet (EXCEL-Microsoft Office Professional)*, graphing, and statistical software (SPSS and Statistica) on desktop computers.

An additional computer-based data acquisition system was also installed in the simulator to provide 16 additional input data channels to record physiological data from the aviator test subjects. This supplementary data acquisition system permitted continuous monitoring of test subject physiological responses to ensure compliance with core temperature and heart rate limits imposed by the USAARL Human Use Committee.

The volunteer pilots were monitored with video cameras when they were in the simulator. Cameras were oriented to provide close-up, uninterrupted, remote monitoring of the appearance and responsivity of the test subjects throughout the simulator sessions. A forward-looking camera fixed to the top of the instrument glare shield allowed remote monitoring of the view out the left front window. The volunteers were informed about the camera system and all provided written recording and photography consent for the study.

Automatic flight control system

Like the actual UH-60 Blackhawk medium transport helicopter, the USAARL UH-60 simulator is equipped with an automatic flight control system (AFCS) which enhances stability and handling qualities (Department of the Army, 1994). The AFCS has four subsystems: The stabilator, the stability augmentation system (SAS), the trim system, and flight path stabilization (FPS). The stabilator, a 14 foot variable angle-of-incidence airfoil, provides control in the pitch axis and a level attitude at a hover. The SAS enhances dynamic stability in all axes, thus preventing "porpoising" in the pitch axis, rolling in the roll axis and "fishtailing" in the yaw axis. The trim system consists of three trims for pitch, roll, and yaw axes. The trim function provides cyclic (pitch and roll) and pedal (yaw) flight control position reference and control gradient to maintain the cyclic stick and pedals at a desired position.

*See list of manufacturers in appendix F.

FPS is also provided for the pitch, roll and yaw axes. FPS provides very low frequency dampening (static stability). FPS functions maintain helicopter pitch attitude/airspeed hold, roll attitude hold, and heading hold and automatic turn coordination.

During simulator flights in this study, the stabilator and SAS were always active. However, the trim system and FPS were deactivated for the 10-minute duration of every other set of standard maneuvers (starting with the second set). This degraded the AFCS thereby requiring more pilot control inputs and significantly increased pilot work load. For the sake of brevity, we henceforth refer to conditions where all components of the AFCS were on as "AFCS on" and conditions where the trim system and FPS components of the AFCS were off as "AFCS off."

Flight profiles (sorties)

The Navy/USMC pilots performed the identical two 2-hour simulator missions flown by the Army aviators in the study by Reardon et al. (1997). The simulator mission profile for each test session consisted of a 2 hour AA sortie, a 10-minute simulated hot-refuel break, then a 2 hour MEDEVAC sortie (appendix A).

Every 30 minutes during each test session, the right seat pilot flew a 10-minute set of standard flight maneuvers (highlighted maneuvers in appendix A). Prior to each set of standard maneuvers, the simulator operator initiated simulated IMC conditions. The pilot then ascended to 2,000 feet to start the maneuver set. After the last standard maneuver in each set, the pilot descended out of IMC to resume visual flight rules (VFR) contour and nap-of-the-earth (NOE) flight along the designated path. The set of standard flight maneuvers was flown four times during each 2 hour flight mission or eight times for the complete 4 hour simulator session. The sets of standard flight maneuvers were well integrated into the underlying scenario.

Flight performance measurement

Performance on all flight segments (standard maneuvers, hover, hover turns, contour, and NOE) were automatically scored by custom software on the USAARL VAX 11/780 computer. Flight performance scores were then downloaded onto desktop computers for analysis and graphing. Scores, indicating how well the test subjects flew each maneuver, were calculated in two steps. First, the scores based on deviations of actual from designated criteria for each parameter in each maneuver were determined using the limits presented in table 2. Second, scores for each of the relevant flight performance parameters were averaged into a single average composite score (ACS) for each maneuver.

Table 2.
Scoring bands for flight performance deviations from target values.

	Maximum deviations for scores of:					
Measure (units)	100	80	60	40	20	0
Heading (degrees)	1.0	2.0	4.0	8.0	16.0	>16.0
Altitude (feet)	8.8	17.5	35.0	70.0	140.0	>140.0
Airspeed (knots)	1.3	2.5	5.0	10.0	20.0	>20.0
Slip (ball widths)	0.0	0.1	0.2	0.4	0.8	>0.8
Roll (degrees)	0.8	1.5	3.0	6.0	12.0	>12.0
Vert. Speed (feet/m)	10.0	20.0	40.0	80.0	160.0	>160.0
Turn Rate (degrees/s)	0.3	0.5	1.0	2.0	4.0	>4.0

Table 3 provides reference values utilized in scoring flight performance for the specific data channels selected for each type of maneuver. *Best* are the target values associated with a 100 percent performance score. *High* are performance values above which performance scores are 0 percent. *Wgt* are weightings for a weighted ACS. *ATM* are the maximum deviations from the target values permitted by aircrew training manual standards (Department of the Army, 1996).

While the right seat pilot was flying standard maneuvers, the left seat pilot used a laptop computer for performance testing with the Multi-Attribute Test Battery (MATB). The MATB is an integrated set of computer-generated, aviation-related, synthetic tasks initially developed by NASA (Comstock and Arnegard, 1992). Unfortunately, due to technical problems, MATB data from the USMC copilots were lost. Therefore, comparison of MATB results for the Navy/USMC vs. Army ensembles were not available for this report.

Physiological measurement methods

Heart rate

Heart rates were recorded with a three lead system using Ver-Med electrodes*. The electrodes were positioned to maximize the R-wave tracing since the leads were connected to a battery powered R-wave counter *. When necessary, permission was obtained to shave a small amount of hair over the preferred electrode locations to obtain sufficient skin-to-electrode contact to ensure signal capture for heart rate determination.

It was noted that the R-wave amplitude in some volunteers varied considerably with changes in posture and depth of breathing. Typically, the aviator volunteers were sitting up straight when the ECG leads were initially applied so that we were usually able to obtain a tall R-wave. Often, however, after they had been flying the simulator for variable lengths of time, R-wave capture would be lost while a backup ECG monitor would indicate a considerably reduced QRS amplitude. Similar changes in QRS morphology noted during test session, therefore, were at least partly attributed to hunching over the controls and the gradual development of more shallow respiratory patterns when pilots were concentrating on flying tasks in the simulator. Changes in electrode impedance due to other factors such as sweat undoubtedly also were important.

Table 3.
Flight performance standards by data channel and maneuver.

LEFT CLIMBING TURN — 5, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Climb rate (ft/min)	01 FROC	Cli	500	160	1	100
Turn rate (deg/sec)	02 FDPSID	Trn	-3	4	1	
Pilot indicated airspeed (knots)	03 FIASR	Asp	120	20	1	10
Roll angle (degrees)	04 FPHID	Rol	-19	12	1	10
Slip ball position (n-d)	05 FSLIPP	Slp	0	0.8	1	

STRAIGHT & LEVEL — 5, Data channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Heading (degrees)	01 UDISHG	Hdg	150	16	1	10
Indicated altitude (feet)	02 FALTI	Alt	2000	140	1	100
Pilot indicated airspeed (knots)	03 FIASR	Asp	120	20	1	10
Roll angle (degrees)	04 FPHID	Rol	0	12	1	10
Slip ball position (n-d)	05 FSLIPP	Slp	0	0.8	1	1

LEFT DESCENDING TURN — 5, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Climb rate (ft/min)	01 FROC	Cli	-500	160	1	100
Turn rate (deg/sec)	02 FDPSID	Trn	-3	4	1	
Pilot indicated airspeed (knots)	03 FIASR	Asp	120	20	1	10
Roll angle (degrees)	04 FPHID	Rol	-19	12	1	10
Slip ball position (n-d)	05 FSLIPP	Slp	0	0.8	1	1

HOVER — 2, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Radar altitude (feet)	01 URDALT	Alt	40	16	1	3
Heading (degrees)	02 UDISHG	Hdg	20	8	1	10

HOVER TURN — 1, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Radar altitude (feet)	01 URDALT	Alt	40	16	1	3

RIGHT STANDARD RATE TURN — 5, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Turn rate (deg/sec)	01 FDPSID	Trn	3	4	1	
Indicated altitude (feet)	02 FALTI	Alt	2000	140	1	100
Pilot indicated airspeed (knots)	03 FIASR	Asp	120	20	1	10
Roll angle (degrees)	04 FPHID	Rol	20	12	1	10
Slip ball position (n-d)	05 FSLIPP	Slp	0	0.8	1	1

CONTOUR — 4, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Radar altitude (feet)	01 URDALT	Ral	80	80	1	100
Heading error (degrees, COMPUTED)	02 *V07	HdE	0	10	1	10
Roll angle (degrees)	03 FPHID	Rol	0	12	1	10
Slip ball position (n-d)	04 FSLIPP	Slp	0	0.8	1	1

NAP OF THE EARTH — 4, Data Channels

Data Channel Description	## Channel	Abrev.	Best	High	Wgt	ATM
Radar altitude (feet)	01 URDALT	Ral	25	25	1	100
Heading error (degrees, COMPUTED)	02 *V07	HdE	0	10	1	10
Roll angle (degrees)	03 FPHID	Rol	0	12	1	10
Slip ball position (n-d)	04 FSLIPP	Slp	0	0.8	1	1

Core temperature

Core temperature was measured with self-inserted YSI 401* rectal thermistors. Prior to use, the temperature sensors were calibrated in a stirred water bath with a precision calibrating thermometer.

The rectal thermistor has proven to be quite safe when used by test subjects who are healthy and do not have inflammatory bowel or rectosigmoid diseases or strictures. Prospective volunteers were medically screened to detect criteria precluding use of such thermistors. None of the volunteers had exclusionary conditions and none incurred adverse effects from their use.

Skin temperature

Skin temperature was measured with four YSI 400 series* surface thermistors which were held in position with collodion and strips of cloth tape. The skin temperature thermistors were placed on the anterior chest, upper lateral arm, lateral thigh, and lateral calf.

Collodion affixed the sensors securely to the skin to prevent sweat associated separation. The skin was inspected daily to avoid placing these sensors on any lesions and to detect any evidence of irritation or metallic ions sensitization reactions. After each use, the sensors were cleaned and allowed to air dry.

Dehydration

Pre- and poststudy session, total undressed and dressed weights were obtained in order to determine the amount of cumulative dehydration and sweating that occurred during each test session.

Prior to starting each test session, the volunteer aviators first urinated and then obtained a nude weight. They self-inserted their individual rectal thermistor. A technician then applied the skin temperature and ECG sensors. Next, test subjects donned the appropriate encumbered MOPP4 ensemble, and a dressed weight was obtained. Before and after each test session, fluids and snack foods were individually weighed. Voided urine was also collected and weights recorded. At the end of each day's test session, a fully clothed weight was again obtained. The ensemble was then removed and a postsession nude weight obtained. Body weight and fluid data were recorded on a form (appendix D) which facilitated subsequent analysis.

Dehydration was calculated by using the term: $100*[(\text{weight}_{\text{sweat loss}} + \text{weight}_{\text{urine output}} - \text{weight}_{\text{water}}) / \text{weight}_{\text{initial nude}}]$. Sweat loss estimate was obtained from the term: $(\text{weight}_{\text{initial nude}} - \text{weight}_{\text{post nude}}) + (\text{weight}_{\text{water}} + \text{weight}_{\text{food}} - \text{weight}_{\text{urine}})$. Total sweat loss minus evaporated sweat permitted assessment of the amount of sweat retained in the ensemble. For each test session, total amounts of sweat, sweat rates, amount of sweat evaporated, and amount retained in the uniform were able to be determined.

Psychological evaluation methods

Mood and symptoms

A 12-question mood and symptoms questionnaire developed for this study was administered before and approximately every 30 minutes after the volunteer pilots began the treadmill session in the environmental chamber (appendix C). Using a 0-10 Likert-type scale (0=none, 10=maximum), the volunteers assessed their sensation of: headache, nausea, stress, anger, depression, energy, heat stress, thirst, workload, boredom, dizziness, and visual difficulty. Hot spot (pressure point discomfort) locations and intensities were also reported.

Profile of mood states (POMS)

Although the results are not reported here, the USMC aviators were administered pre- and posttest session POMS questionnaires to maintain the test condition comparable to that experienced by the Army aviators. The POMS is a list of 65 questions utilizing a 5-point adjective rating scale. It provides a statistically derived factor inventory as a method of identifying and assessing transient and fluctuating affective states (McNair et al, 1981). The POMS scoring process produces one total mood disturbance score and subscores for six mood categories (tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment). The POMS was administered in the test subject preparation room prior to the simulated preflight (pretest) and again in the recovery/cool-down room immediately after completing each simulator session.

Task load index (TLX)

The NASA TLX, originally developed by the Human Performance Research Group at the NASA Ames Research Center (Hart and Staveland, 1988), was administered to the right-seat pilot at the completion of each set of standard maneuvers and to the left-seat pilot immediately after completing each 10-minute MATB performance test. Using a 0-20 Likert-type scale, the volunteers provided their assessment of the following sensations: mental demand, physical demand, temporal demand, own performance, effort, and frustration. Results are presented below as mean rating for each of the component TLX questions. The actual composite index values were not calculated or reported because of ambiguity with respect to interpretation and selection of appropriate weighting values.

Data analysis

Due to the limited number of test subjects in this evaluation, hypothesis testing using standard parametric techniques such as multivariate analysis of variance (MANOVA) or analysis of variance (ANOVA) was not feasible. Even the acceptability of nonparametric hypothesis testing techniques was dubious. Therefore, comparison of results for the Navy/USMC vs. Army uniforms are presented graphically. In the subsequent charts and graphs, the 95 percent confidence interval (CI) (mean $\pm$ 2 standard errors) for the Army MOPP4-hot reference group defines the range within which the mean for the Navy/USMC results must fall to justify a conclusion of no statistically significant difference between responses across the two uniforms (see Dawson-Saunders and Trap, 1994, Chapter 7).

Results

Test subjects

From 16-20 June 1997, four male USMC aviators (two UH-60 crews) voluntarily participated in this study. All completed the study without injury or complications.

Because the USMC aviator volunteers were available for only 1 week, training and heat stress acclimatization were necessarily limited to 2 days. For acclimatization the volunteers walked on treadmills at 3 mph, 0% grade in the USAARL environmental chamber under hot conditions (100°F, 20%RH) for 60 minutes on the first day and 10 minutes on the second day. During testing the volunteers underwent one test session consisting of wearing the Navy/USMC encumbered MOPP4 ensemble in a hot (100°F, 50 percent RH) UH-60 cockpit condition. This was an approved modification of the 1996 USAARL research protocol for evaluating an equivalent U.S. Army encumbered MOPP4 rotary-wing ensemble. In that study, time permitted 2 weeks of training, acclimatization, and testing for each crew. Identical physiological and flight performance response variables were measured in both studies and the salient comparisons summarized below.

The two independent groups of aviator volunteers (USMC vs. Army) were similar except that the USMC pilots were heavier and had significantly greater total career flight hours but fewer UH-60 aircraft and simulator flight hours (figure 4). Spearman correlational analysis did not reveal statistically significant associations between aviator characteristics and subsequently described physiological or flight performance results.

Comparability of environmental conditions

As indicated in figure 5, time averaged simulator temperature and humidity were very close to levels prescribed in the research protocol (100°F and 50 percent RH, respectively) and did not statistically differ between the 1997 Navy/USMC and 1996 Army ensemble evaluations.

Physiological results

Endurance

As depicted in figure 6, in contrast to a nominal fully completed mission time of ~300 minutes (20 minute simulated preflight treadmill walk plus two 2-hour sorties separated by a 10 minute simulated hot refuel break), mean crew endurance in the MOPP4-hot condition for the Navy/USMC and Army ensembles were 132 and 98 minutes, respectively. Crew endurance was determined by the interval from starting the simulated preflight simulation on the treadmill to reaching the maximum permissible core (rectal) temperature (102.5°F) in the simulator. For the

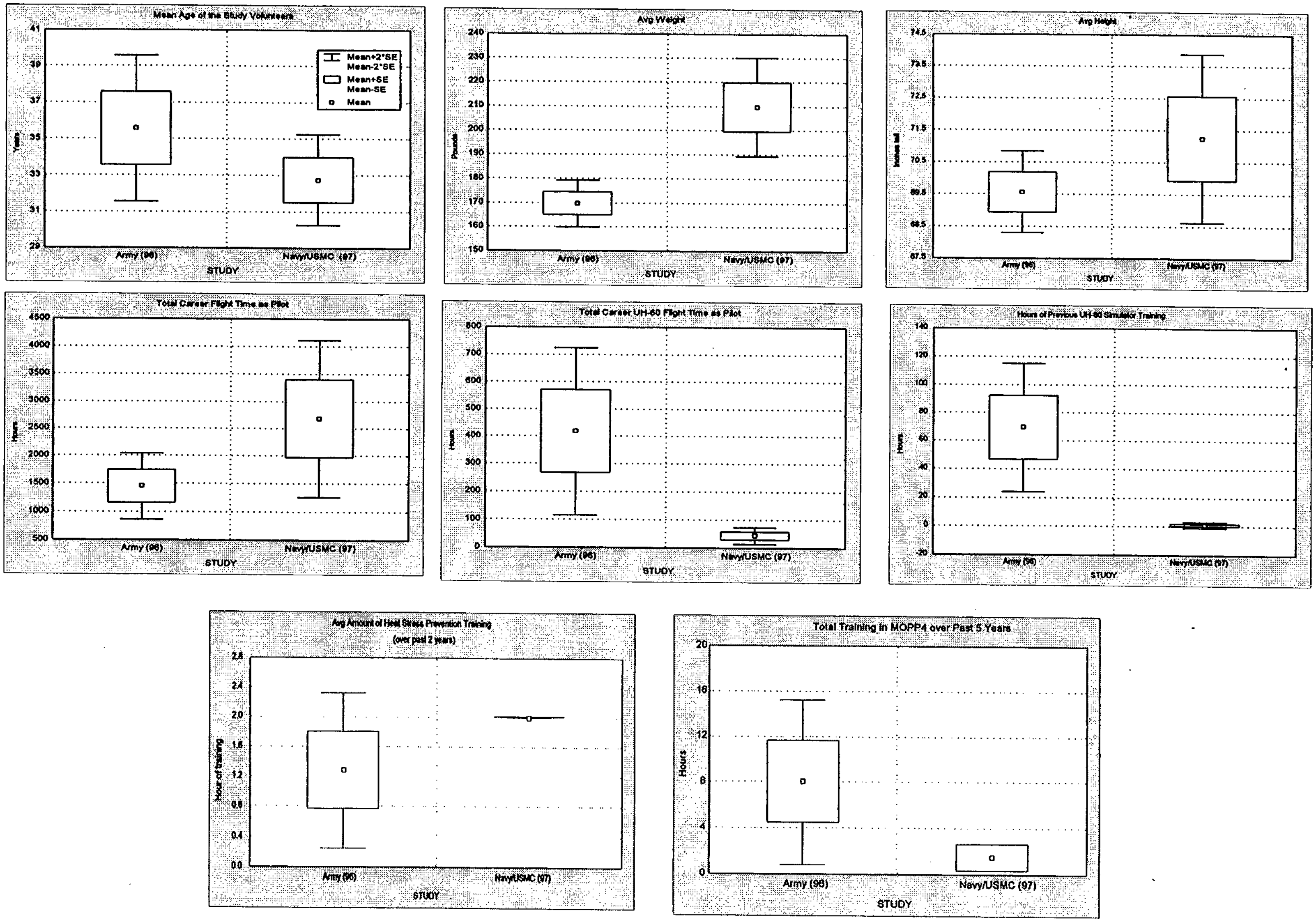
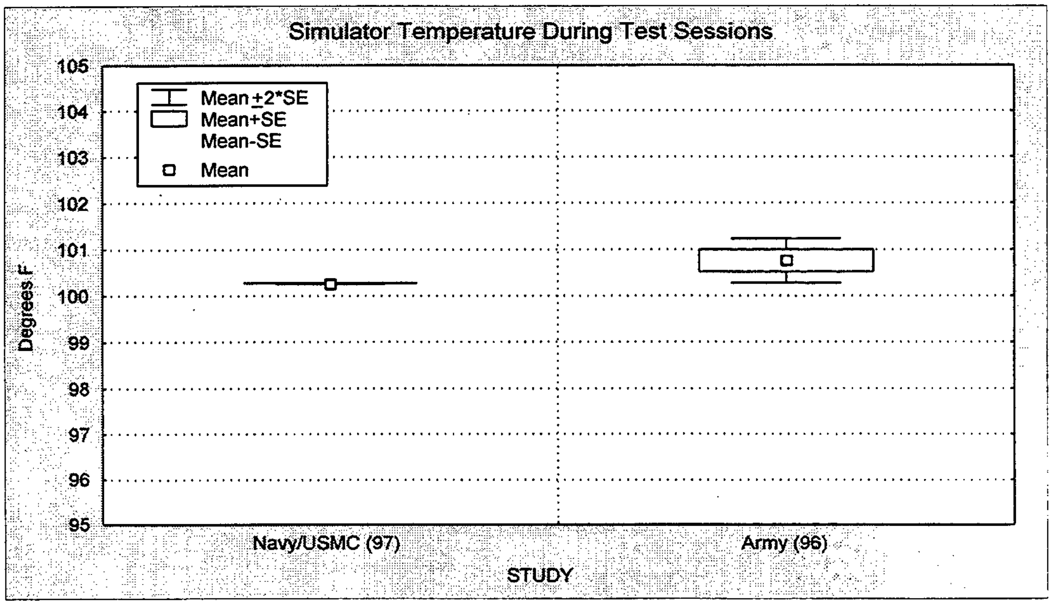


Figure 4. Army vs. USMC test subject characteristics.



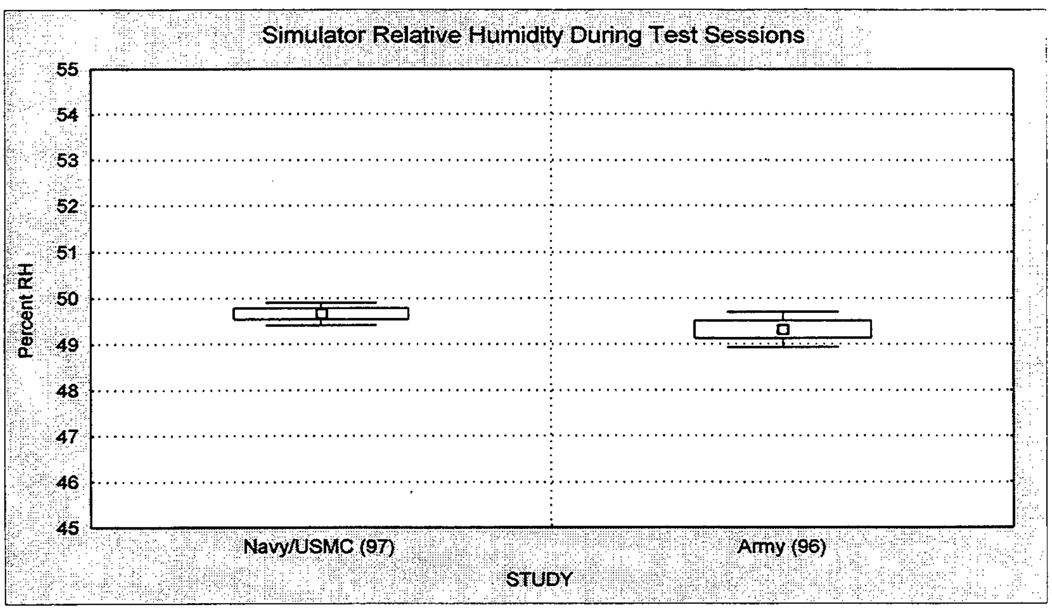


Figure 5. Comparability of test session environmental conditions.

Army cohort, crew endurance was limited, in a few cases, by progressive heat stress symptoms rather than core temperature limit.

Comparing endurance, core temperature, and heart rate profiles for the Navy/USMC vs. Army ensembles by individuals instead of two-person crews was problematic because of censored endurance and physiological data for some of the Army aviators who were withdrawn (but who could have continued) due to the companion crewmember reaching tolerance or core temperature limits. In contrast, the USMC pilots were all allowed to continue to their individual limits. To avoid this censored data problem, therefore, comparisons should be made based on the endurance of two-person crews.

Core temperature and heart rate

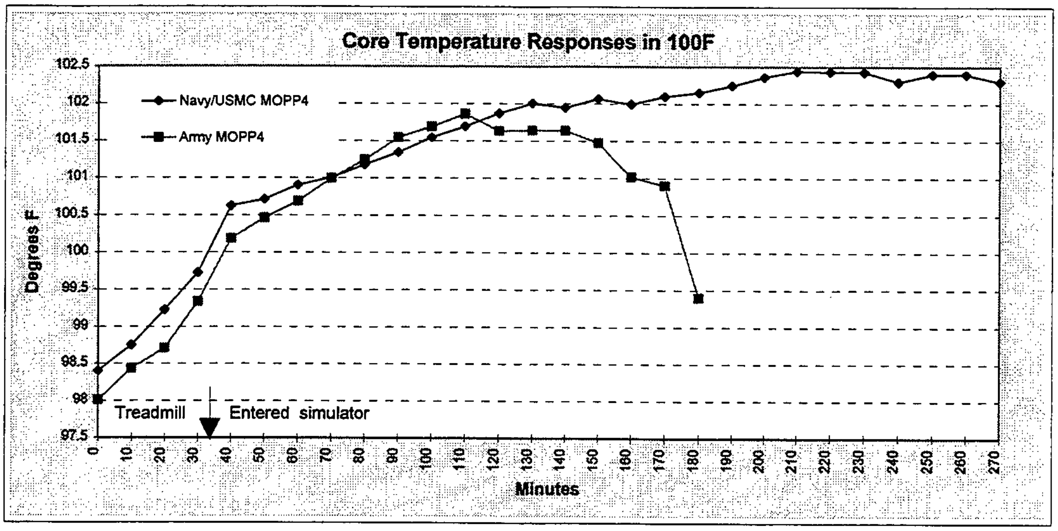
Averaged core temperature vs. time profiles (figure 7) for the Navy/USMC and Army encumbered MOPP4 ensembles were not substantially different for the first 120 minutes. Mean heart rates, however, were lower for the Navy/USMC ensemble during the simulator sorties (figure 8).

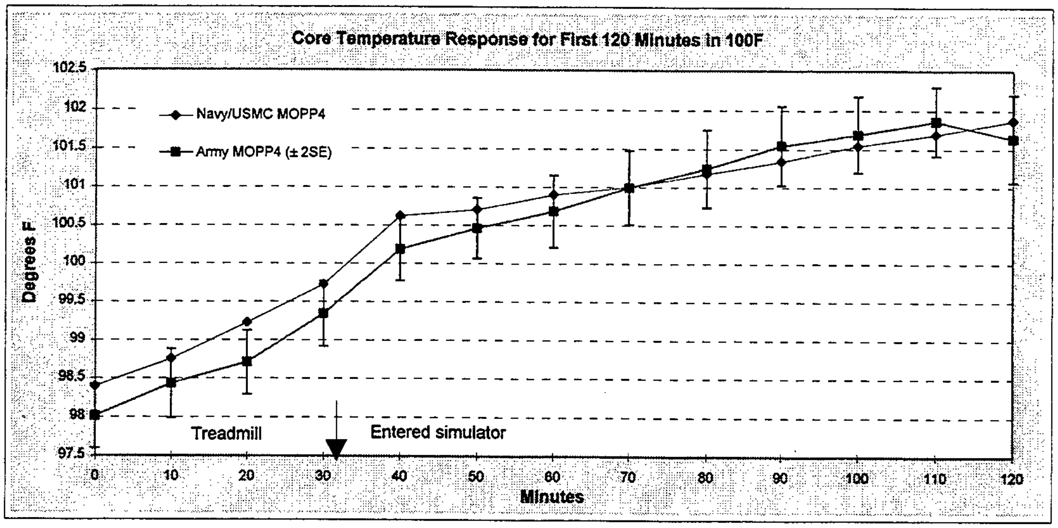
Skin temperatures

Compared to the Army ensemble, average maximum skin temperatures (figure 9) for the Navy/USMC encumbered MOPP4 ensemble, were 0.57°F and 0.90°F greater over the anterior chest and lower lateral leg, respectively, and 0.53°F and 1.00°F less over the upper lateral arm and lateral thigh, respectively. This indicated regional differences in core-to-skin temperature gradients for the Navy/USMC vs. Army ensembles thereby obviating a meaningful comparison of calculated estimated total body heat gain based on core temperature alone.

Fluid balance and dehydration

In the hot-MOPP4 condition (table 4 and figure 10), the average sweat rate for the aviators in the Navy/USMC ensemble was substantially lower (1033 cc/hr) than for the Army ensemble (1494 cc/hr). Likewise, the Navy/USMC ensemble allowed a greater percentage of sweat evaporation (52 ± 2.6 percent SE) than the Army ensemble (27 ± 3.2 percent). Conversely, percentage of sweat retained in the uniform was greater for the Army (73 ± 3.2 percent) than the Navy/USMC (48 ± 2.6 percent) ensemble. These differences were probably due to greater water vapor permeability of the Navy/USMC CB protective undergarment versus the CB BDO because the masks, overgloves, overboots, and ballistic plates for both ensembles were essentially completely impermeable to sweat. Average total water intake was slightly greater for the pilots wearing the MOPP4 Navy/USMC ensemble (1112.5 cc) than for those wearing the MOPP4 Army ensemble (961.2 cc) . However, since the average time in uniform for the Army pilots was less than the Navy/USMC (106.62 minutes versus 188.50 minutes), the Army pilots had a greater hourly average water intake rate (546.8 cc/hour) than the Navy/USMC pilots (342.6 cc/hour). The latter difference could have been related to the higher average sweat rate for the Army pilots and/or to disparities between the ensembles in the protective mask drinking tube mechanisms and canteen interfaces.





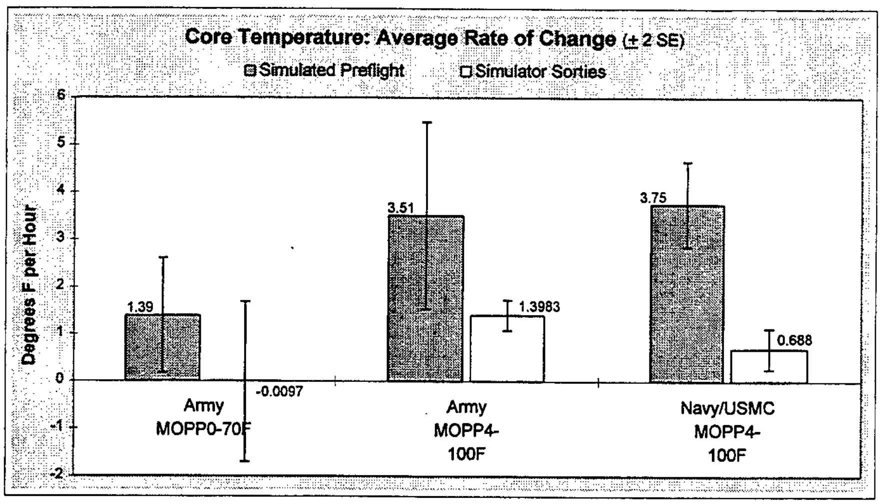


Figure 7. Core temperature comparisons.

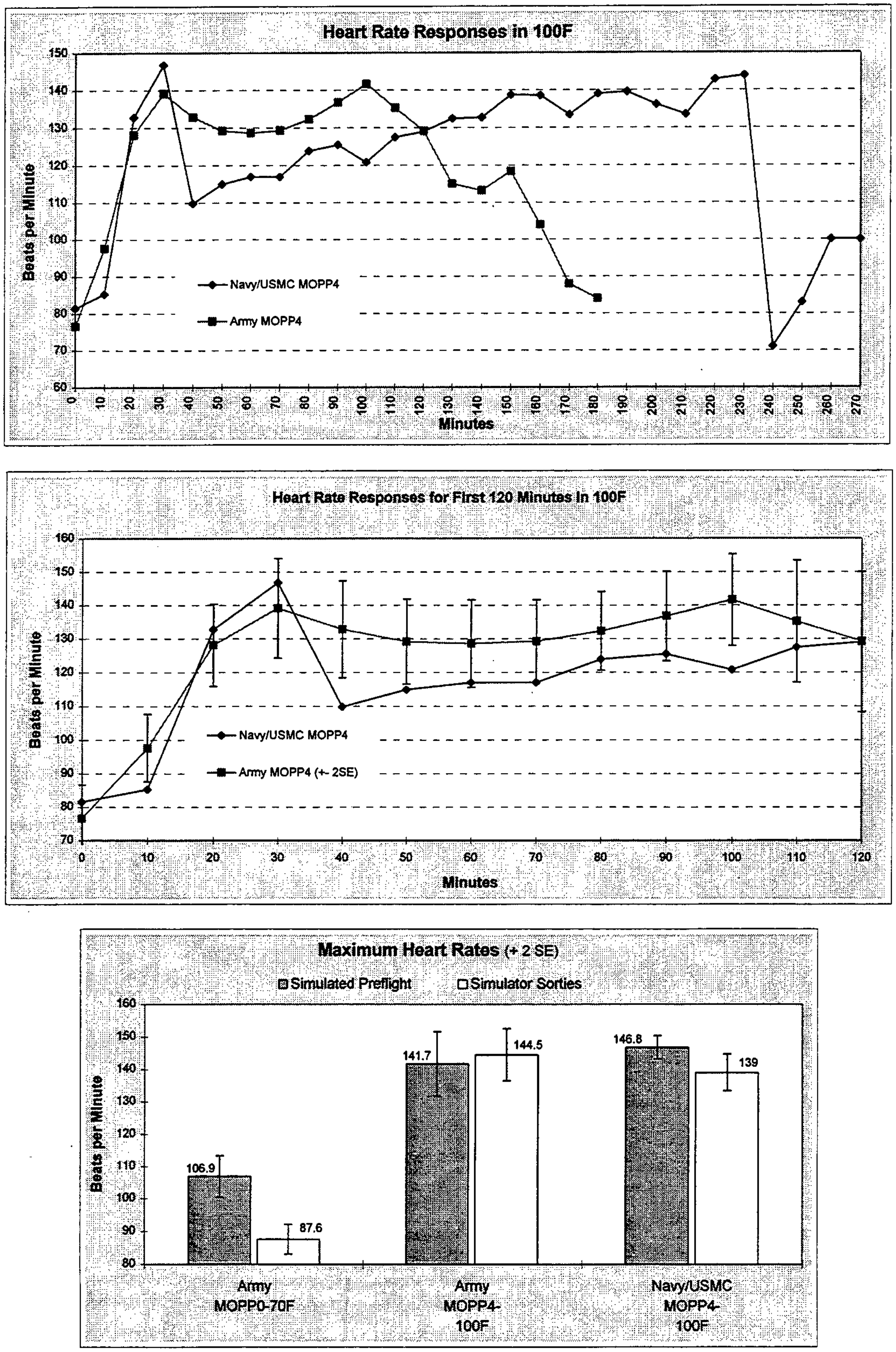


Figure 8. Heart rate comparisons.

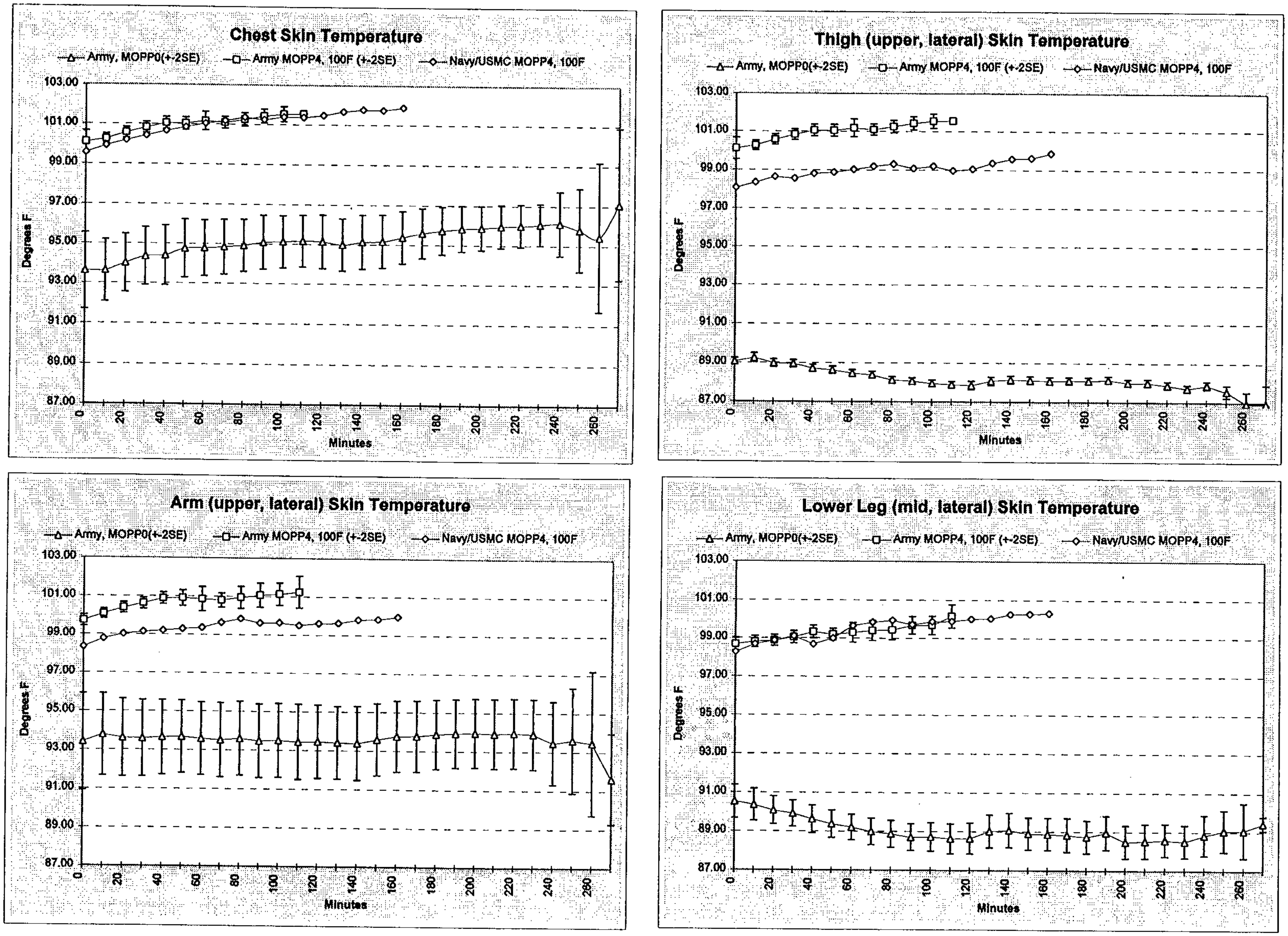


Figure 9. Skin temperatures.

Table 4.

Average sweat and fluid intake/output rates (cc/hr)

	Navy/USMC MOPP4, 100°F	Army MOPP4, 100°F	Army MOPP0, 70°
Sweat total	1033.60	1494.29	103.85
Sweat retained	504.93	1101.46	17.18
Sweat evaporated	528.67	392.83	92.08
Water intake	342.58	546.80	181.43
Urine output	166.19	175.44	111.47

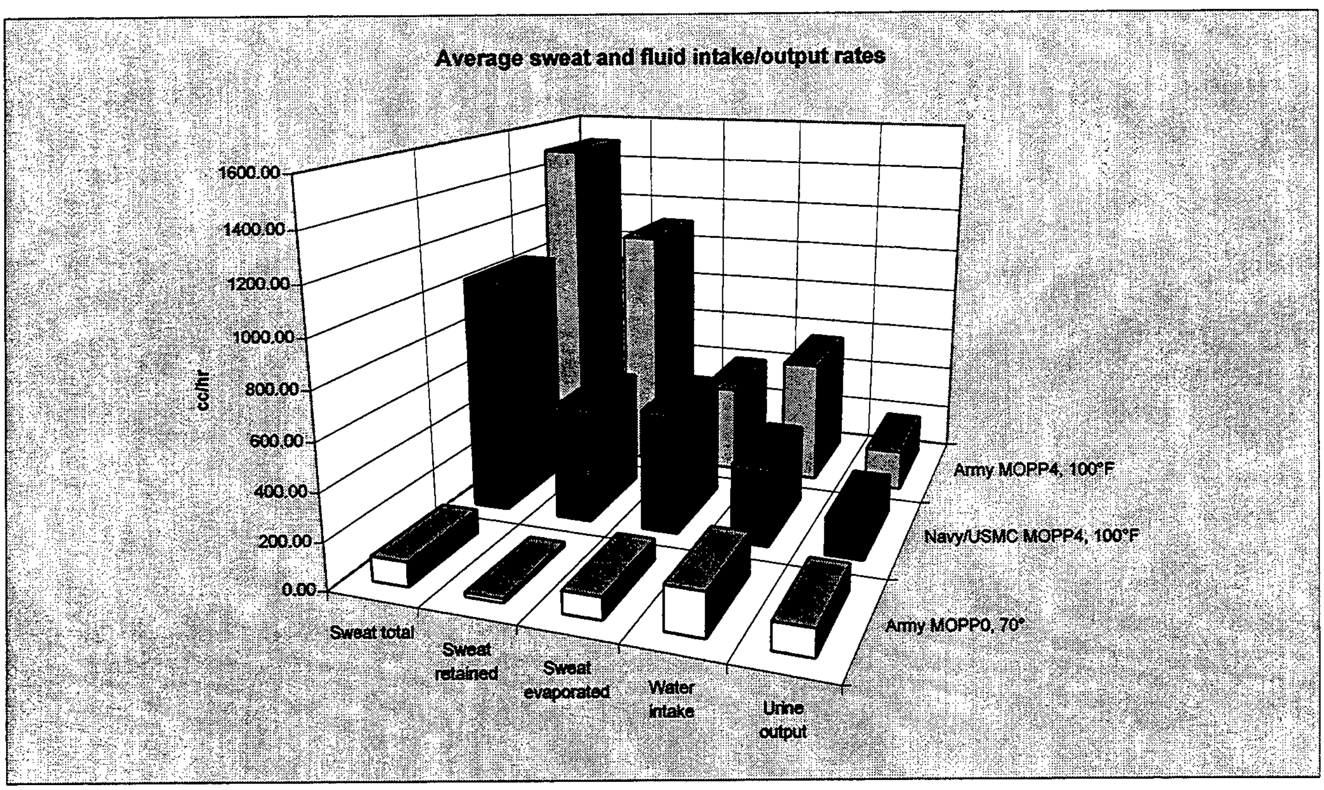


Figure 10: Average sweat and fluid intake/output rates

Psychological results

Mood and symptoms

As indicated in figures 11 and 12, average aviator ratings for mood and symptoms in the MOPP4-hot condition for both the Navy/USMC and Army ensembles did not substantively differ except that the USMC pilots seemed to have less visual difficulty with their CB mask. The Army pilots had greater proportion of hot spot discomfort complaints over the head and back (figure 13). This was due to bothersome pressure points from their CB mask as well as the life raft which hung down over the lower back.

Task load ratings

Graphical comparison of test subject ratings for the six components of the TLX are shown in figure 14. In general, ratings for mental, physical, and temporal task demand were lower for the Navy/USMC MOPP4 ensemble. The Army MOPP4 ensemble elicited higher ratings for overall effort. Consistent with this were generally higher ratings for the Navy/USMC ensemble for task performance satisfaction. These ratings were averages of the TLX component questions administered to the pilot at the end of each 10-minute set of standard maneuvers and to the copilot at the end of each concurrent 10-minute MATB performance test. The preparatory cue for responding to the TLX questionnaire included an instruction that the responses were to be with respect to the preceding 10-minute task. Previous repeated measures TLX component data (Reardon, et al., 1997) did not reveal statistically significant differences in mean ratings for standard maneuvers vs. MATB.

Performance results

Flight performance scores

The right seat pilots alternated use of the AFCS for each iteration of the set of standard maneuvers (SL, RSRT, SL, LCT, SL, LDT, SL) as specified in the flight scripts. Hovers, hover turns, and NOE and contour segments, however, were always flown with the AFCS on.

Qualitatively, (see figures 15 and 16) flight performance (as measured by average composite flight performance score) was not consistently different for the Navy/USMC vs. Army aviator ensembles in the hot condition. The only apparent exception was higher HOVT performance scores (with AFCS on) for the Navy/USMC ensemble. There was no obvious explanation for this result. Better visibility with the Navy/USMC CB mask is not a likely explanation since the Army HOVT scores were approximately the same for both MOPP0-hot and MOPP0-cool conditions. Despite some variability in mean flight performance scores for the Navy/USMC vs. Army MOPP4 ensembles, figure 17 shows that there were no significant differences in mean number of potentially dangerous or lethal flight incidents (e.g. controlled flight into terrain, tail rotor strikes, etc.).

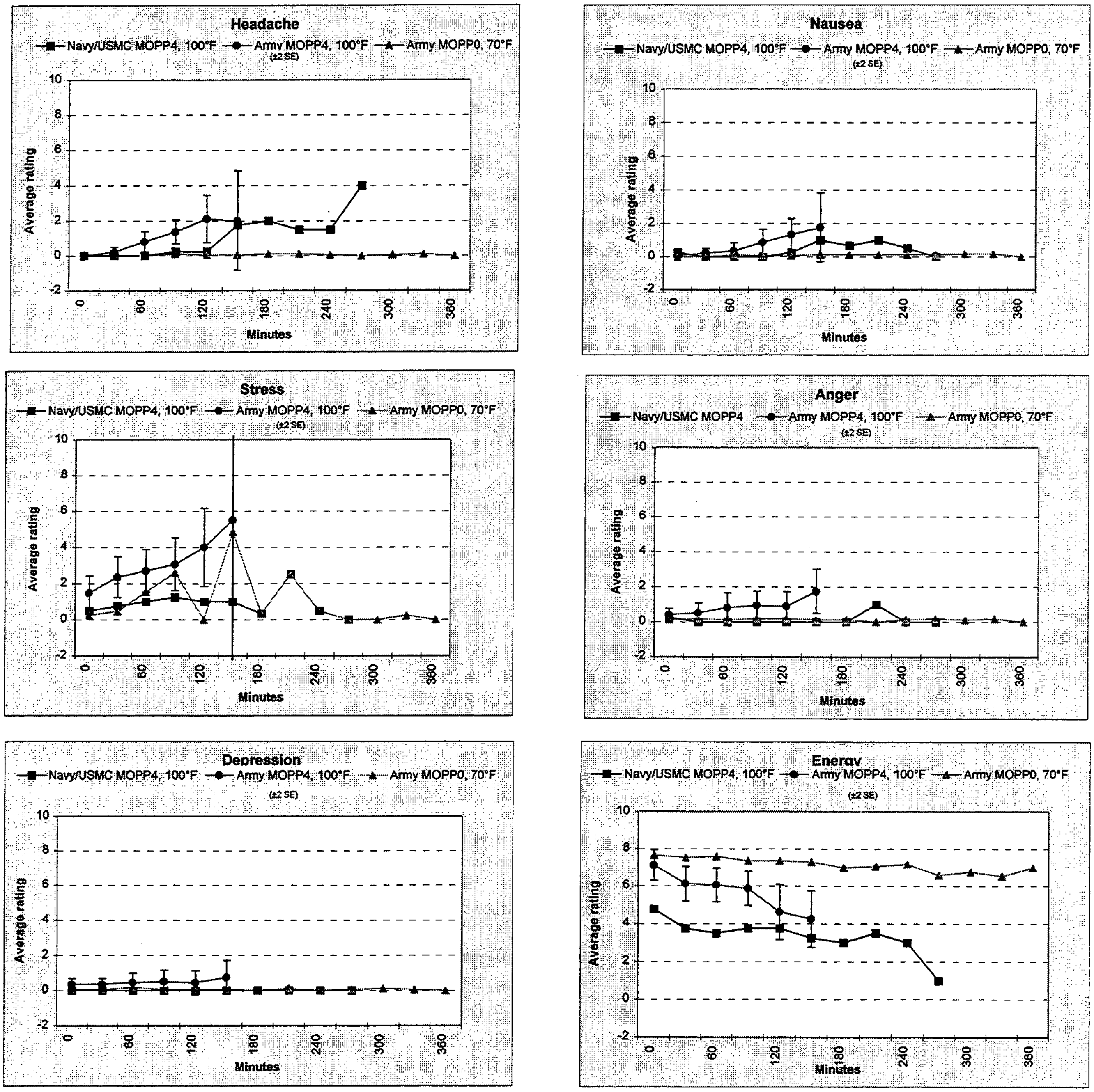


Figure 11. Mood and symptoms: Average ratings.

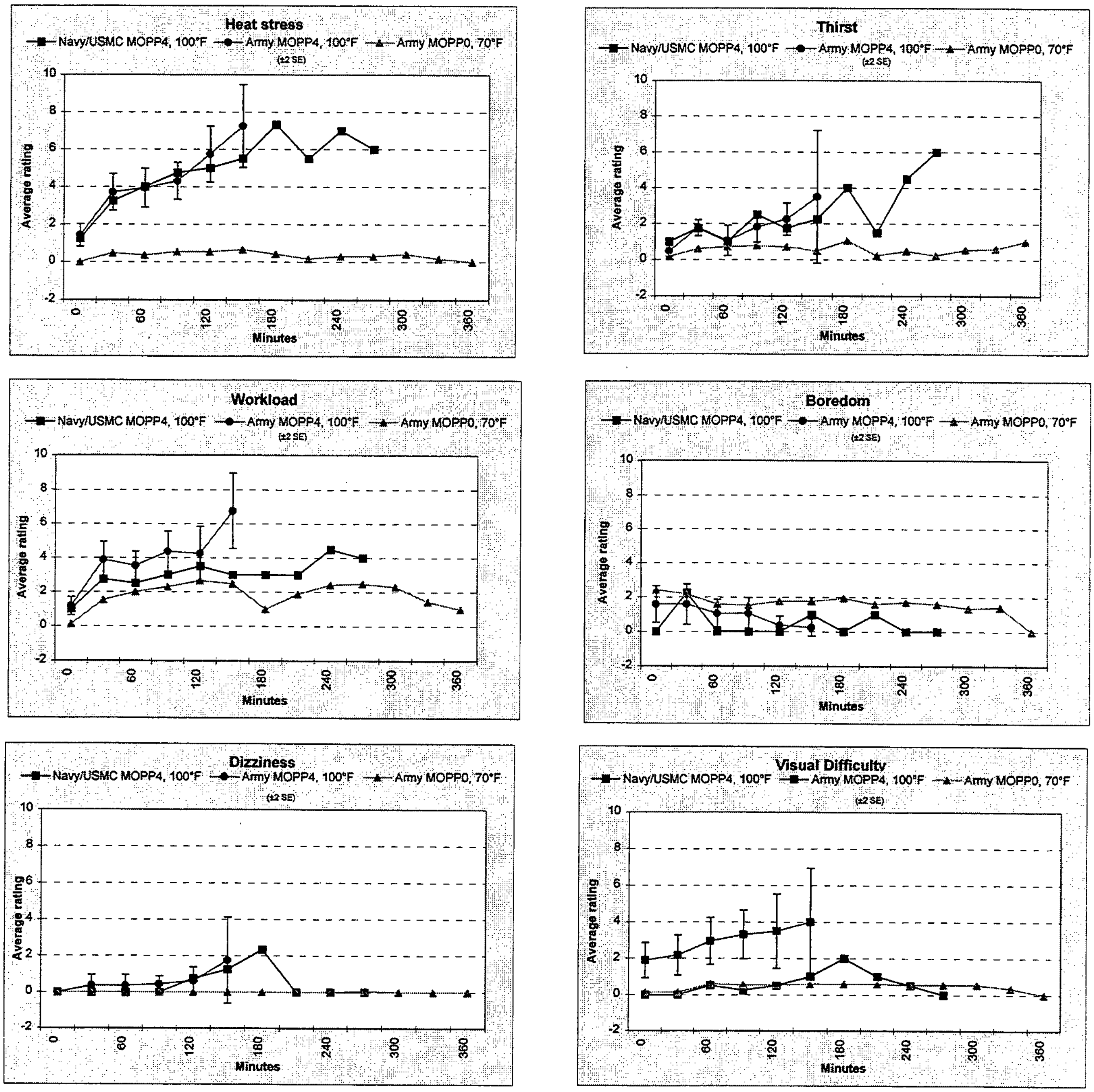


Figure 12. Mood and symptoms: Average ratings (continued).

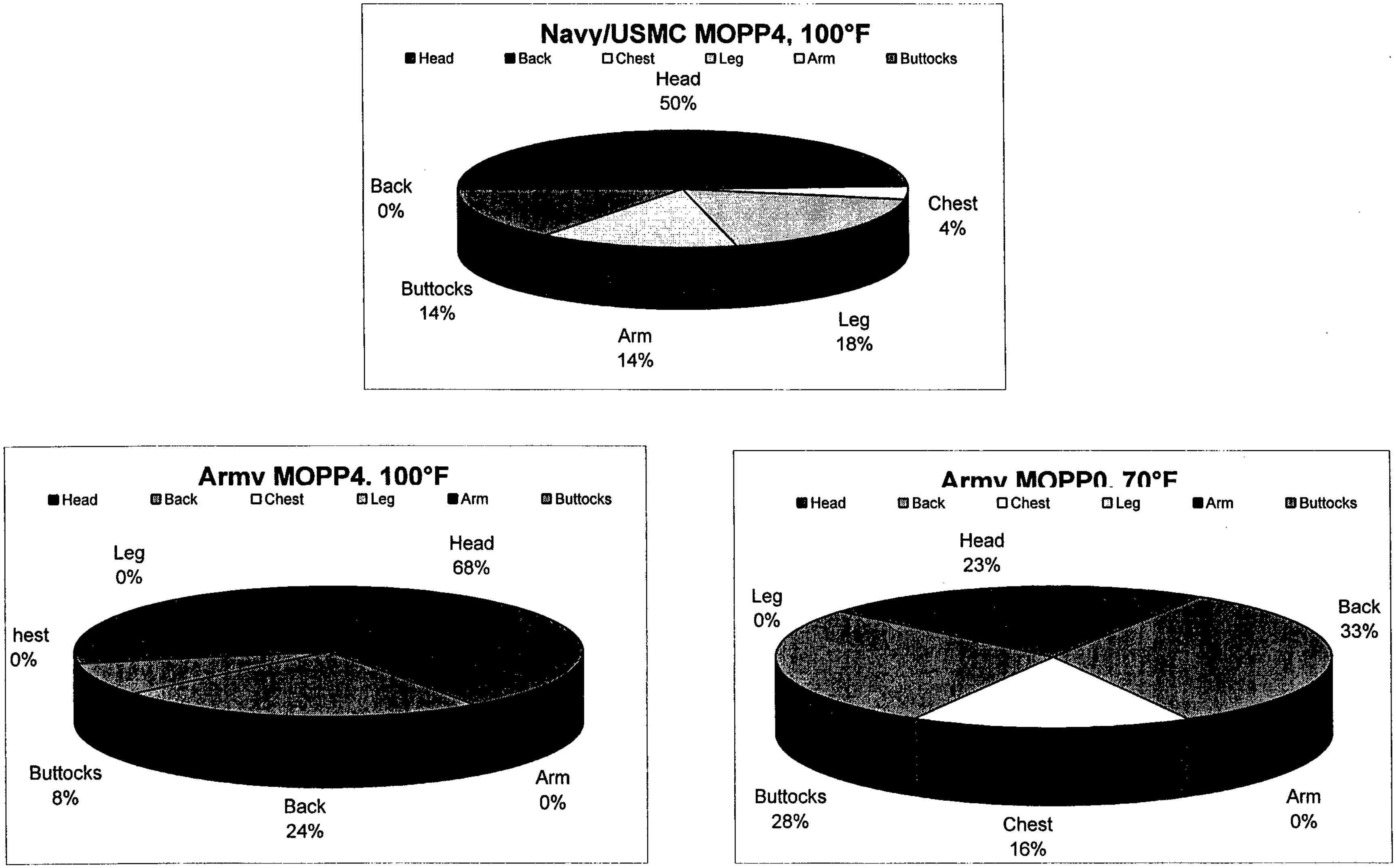


Figure 13. Hot spot distribution.

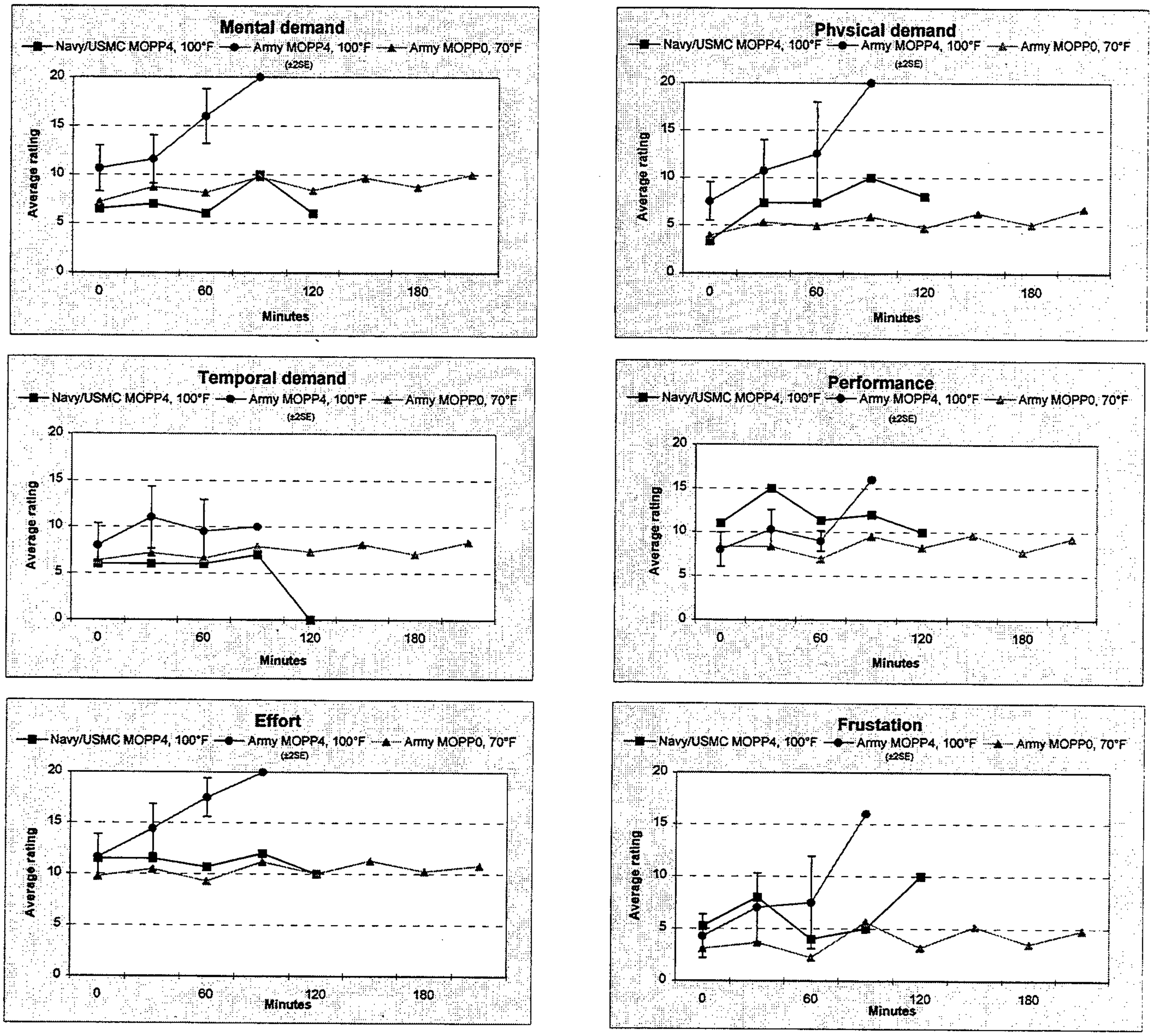


Figure 14. Task load ratings.

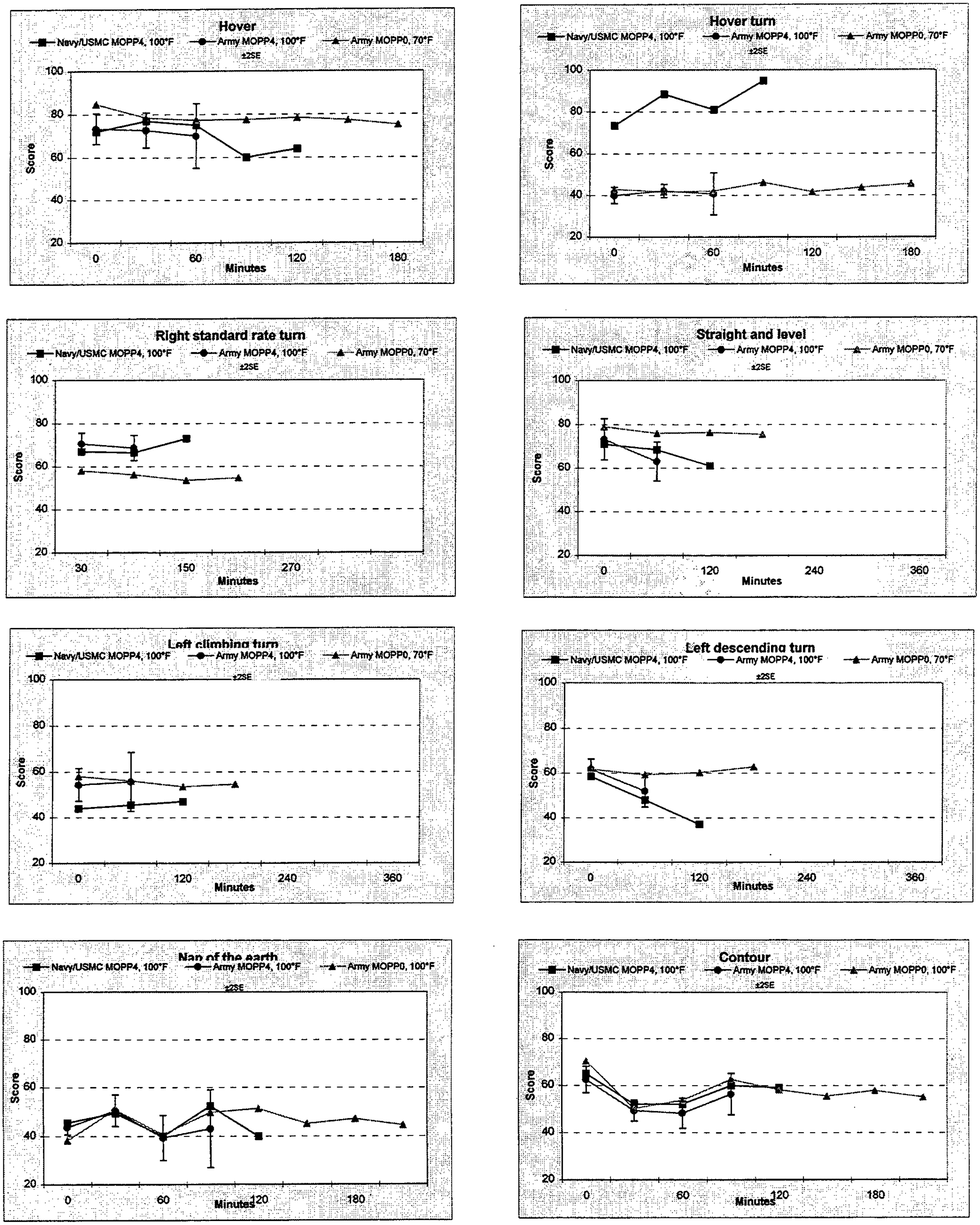


Figure 15. Average composite flight performance scores: AFCS on.

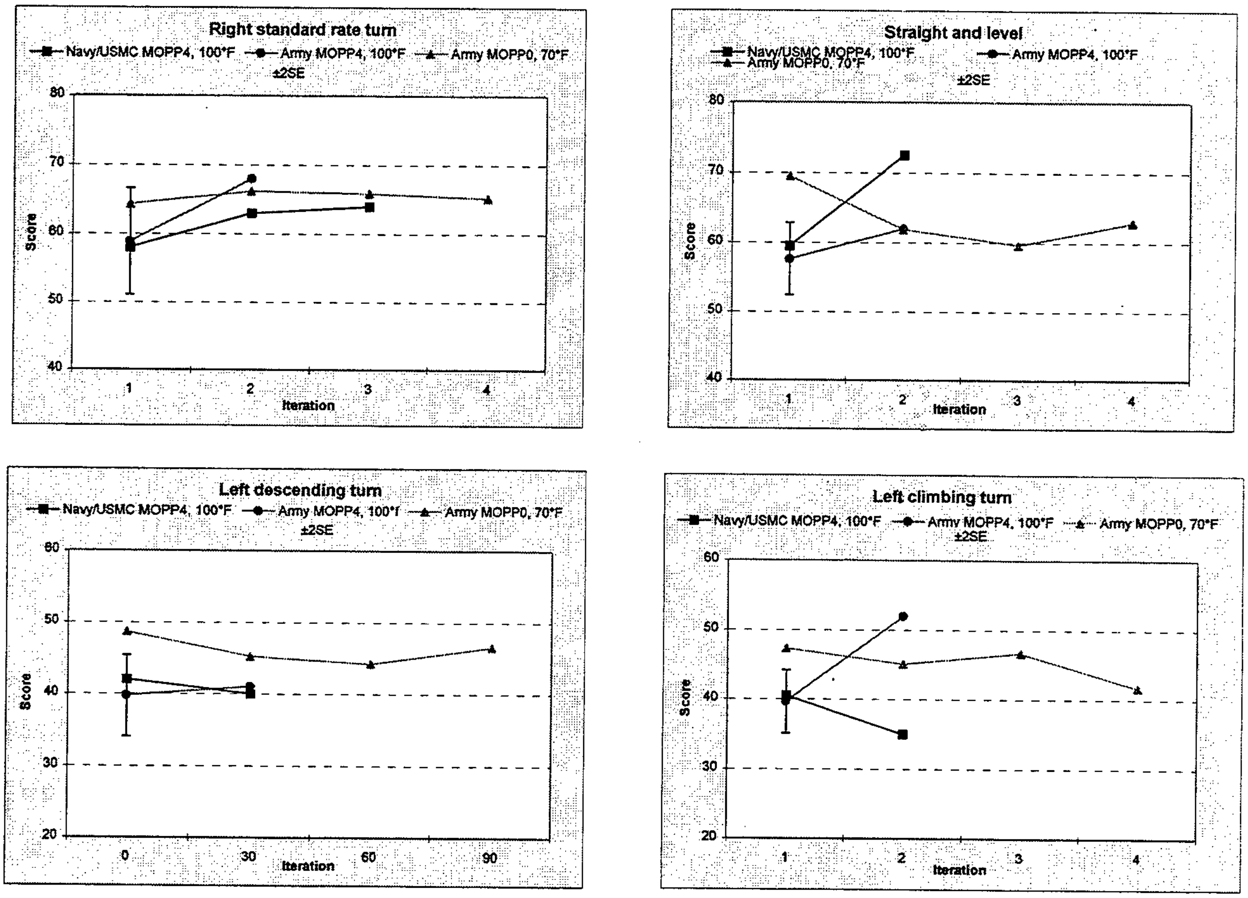


Figure 16. Average composite flight performance scores: AFCS off.

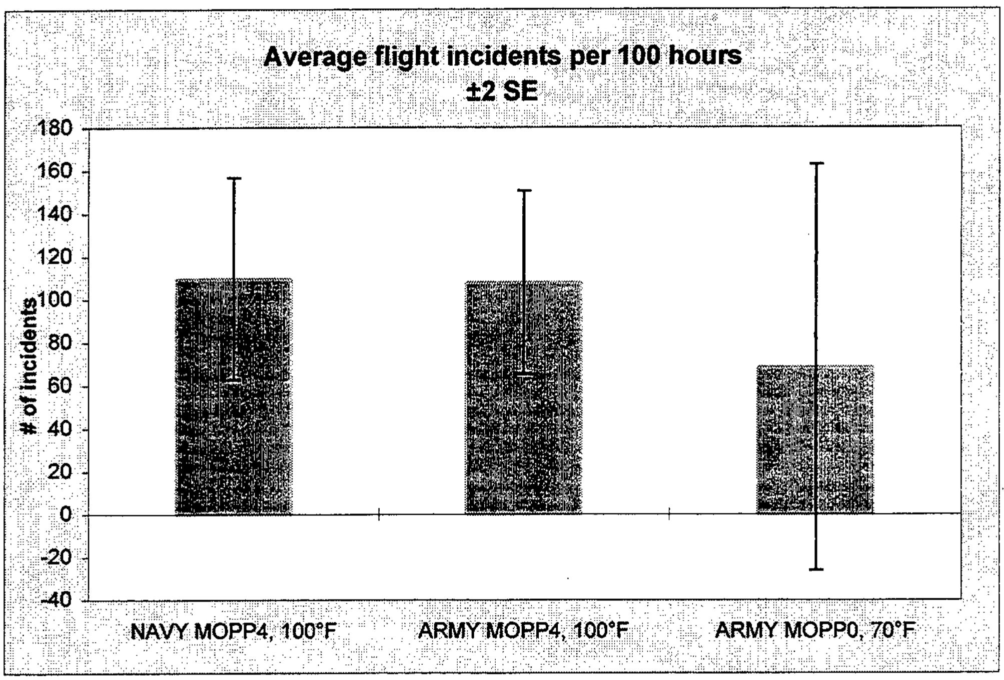


Figure 17. Simulator incidents.

MATB

Because of technical problems, MATB data from the USMC copilots were lost. It was therefore not possible to compare Navy/USMC vs. Army performance on this computer-based psychomotor performance test.

Discussion

The physiological responses in the hot condition (100°F, 50 percent RH) for both the Navy/USMC and Army encumbered MOPP4 rotary-wing ensembles were similar. Both exhibited rapid elevations in core temperature and heart rate. These results were consistent with those reported by Knox III et al. (1983) and Thornton et al. (1992). Regional differences in core-to-skin temperature gradients were evident, with the Navy/USMC ensemble favoring heat dissipation over the later arms and thighs but less heat dissipation across the chest. Although similar average core temperature profiles suggested comparable body heat accumulation, the regional differences in temperature gradients indicated otherwise. Since endurance was nominally 52 minutes greater and heart rates slightly lower for the aviators wearing the Navy/USMC ensemble, one could assume that heat gain, normalized for body mass, was probably less for the aviators in that ensemble. Results showed that the Navy/USMC ensemble permitted evaporation of a significantly greater percentage of sweat compared to the Army ensemble. This suggests that the Navy/USMC CB undergarment is more water permeable and retains less sweat than the thicker Army CB overgarment.

Questionnaire responses showed a time dependent progression of adverse symptoms in the hot condition for both the USMC and Army volunteers. There was no question that they felt heat stressed. The data indicated that the Navy/USMC ensemble was possibly more comfortable, however, questionnaire responses are fraught with the potential for intergroup rating biases making it difficult to arrive at definitive conclusions or comparisons for these independent samples. A repeated measures design is suggested as a safer method for determining true differences in comfort for the two ensembles. The data, however, did suggest that the Navy/USMC CB mask/helmet combination resulted in fewer hot spots and provided better visibility. On the other hand, this investigator observed several instances wherein the Navy/USMC CB mask caused troublesome restriction in head and neck motion (flexing and turning).

There did not appear to be substantial flight performance differences between the two ensembles. Although the USMC pilots had less UH-60 simulator experience than most of the Army pilots, they had greater overall flight hours. It is suspected that these two factors balanced out during the test sessions. Flight performance results were generally consistent with similar previously reported results (e.g., Hamilton et al., 1982 and Thornton et al., 1992). Well trained aviators appear to be capable of defending flight performance despite relatively severe or prolonged heat stress exposure. This is a manifestation of a some type of nonlinear, threshold effect, relationship between flight performance and severity and/or duration of heat stress exposure. Although this study was not designed to corroborate this hypothesis, results suggest that flight performance is degraded at a relatively slow rate until sudden and drastic deterioration occurs as physiological or symptomatic collapse become imminent. The relative paucity of blatant flight performance decrements in moderate or short duration hot conditions, therefore, should not be interpreted as indicating that heat stress is not a potentially serious problem for helicopter pilots.

Finally, we reiterate caution that the number of aviators tested was insufficient to justify statistically decisive conclusions. The data from this study, however, suggested that the Navy/USMC encumbered MOPP4 ensemble was somewhat better, overall, at allowing dissipation of body heat primarily due to less resistance to sweat evaporation. The Navy/USMC CB mask was, by its nature, very impermeable and also restricted head and neck movements. However, it seemed to cause less hot spot discomfort and afforded greater visibility than the Army equivalent. Although in some respects the Navy/USMC encumbered MOPP4 ensemble, as a whole, was less thermally burdensome, it is possible that some of the Army components allowed better regional thermoregulation. This study, however, was not designed or capable of discerning differences for the Navy/USMC vs. Army aviator ensemble components taken individually.

Conclusions

This comparison of Navy/USMC vs. Army encumbered MOPP4 aviator ensembles in heat stress indicated that the Navy/USMC ensemble permitted a higher rate of heat dissipation due to less sweat retention in the uniform and higher percentage of evaporated sweat. This resulted in somewhat longer physiological heat stress tolerance and mission endurance times for the Navy/USMC ensemble. Flight performance seemed to be independent of type of MOPP4 ensemble. This study, however, lacked the statistical power to confirm the apparent lack of performance differences across the two tested ensembles. This was due to the small number of test subjects caused by restricted aviator availability, short customer set timelines, and limited funding. The small number of test subjects also reduces confidence that the differences noted in this study would be sustained if a larger, and presumably more representative, sample of Navy/USMC and Army helicopter pilots were studied. Likewise, the study was not designed to compare the differential effects of the individual components on thermoregulation and performance. Nonetheless, there were some obvious and significant differences in material, style, mode of wear, and weight between the Navy/USMC and corresponding Army ensemble components. This suggested that a mix of the tested components might offer a more favorable off-the-shelf solution for minimizing rates of heat strain progression and decrements in endurance and performance. Model-based analysis is a possible method of testing such a hypothesis which could avoid a complex, expensive, and protracted evaluation of every permutation of components. However, the coefficients and parameters in an appropriate quantitative predictive thermoregulatory model used for this purpose would require obtaining the specific biophysical properties (e.g., insulation and water vapor permeability values) for each of the ensemble components.

References

ATCOM. 1995. Operational Requirements Document for the Air Warrior (draft). St. Louis, MO.: Aviation and Troop Command.

Breckenridge, J.R. and Levell. 1970. Heat stress in the cockpit of the AH-1G Hueycobra helicopter. Aerospace Medicine. 41(6):621-626.

Berglund, L., Gonzalez, R. and Gagge, A. 1990. Predicting human performance decrement from thermal discomfort and ET. The Fifth International Conference on Indoor Air Quality and Climate. J. A. J Stolwijk (Ed.), pp. 215-220, Toronto, Canada.

Comstock, J.R., and Arnegard, R.J. 1992. The Multi-Attribute Task Battery for human operator workload and strategic behavioral research. Hampton, VA: NASA Langley Research Center, NASA Technical Memorandum 104174.

Dawson-Saunders, B. and Trapp, R. 1994. Basic & Clinical Biostatistics. 2nd ed. East Norwalk, CN: Appleton & Lange.

Department of the Army. 1994. Operator's manual for Army models, UH60A helicopters, UH60L helicopters, EH60A helicopters. Technical Manual 1-1520-237-10 Washington, DC: U.S. Government Printing Office.

Department of the Army. 1996. Aircrew training manual, utility helicopter, UH-60. U.S. Army training circular, TC 1-212. Washington, DC: U.S. Government Printing Office.

Epstein, Y., Strochein, L.A., and K.B. Pandolf. 1987. Predicting Rectal Temperature Response to Work, Environment, and Clothing. European Journal of Applied Physiology. 56: 495-500.

Froom P., Shochat I., Strichman L., Cohen A., and Epstein Y. 1991. Heat stress on helicopter pilots during ground standby. Aviation, Space, and Environmental Medicine. 62: 978-81.

Gonzalez, R.R. 1988. Biophysics of heat transfer and clothing considerations. In: Human Performance Physiology and Environmental Extremes (Eds: Pandolf, K.B., Sawka, M.N., and Gonzalez, R.R.). Indianapolis, IN: Benchmark Press, Inc.

Hamilton, B.E., Simmons, R.R., and Kimball, K.A. 1982. Psychological effects of chemical defense ensemble imposed heat stress on Army aviators. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-6.

Hancock, P.A. 1982. Task categorization and the limits of human performance in extreme heat. Aviation, Space, and Environmental Medicine. 53:8 778-784.

Hart S.G., and Staveland, L.E. 1988. Development of NASA-TLX (Task Load Index): Results of Emperical and Theoretical Research. In Eds. P.A. Hancock and N. Meshkati. Human Mental Workload. Amsterdam: North Holland Press.

Knox III, F.S., Nagel, G.A., Hamilton, B.E., Olazabel, R.P., and Kimbal, K.A. 1983. Physiological impact of wearing aircrew chemical defense protective ensembles while flying the UH-1H during hot weather. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-4.

Kobrick J.L. and Johnson R.F. 1992. Effects of Hot and Cold Environments on Military Performance. Natick, MA: U.S. Army research Institute of Environmental Medicine. Technical Report T7-92.

Lussier J.W. and Fallesen J.J. 1987. Operation of the tactical computer terminal in mission oriented protective posture 4 clothing. Fort Levenwoth, KS: Army Research Institute.

McNair, D., Lorr, M., and Droppleman, L. 1981. Edits Manual for the POMS: Profile of Mood States. San Diego, California: Educational and Industrial Testing Service.

Muza S.R., Banderet L., and Forte V.A. 1995. The Impact of the NBC Clothing Ensemble on Respiratory Function and Capacities During Rest and Exercise. Natick, MA: U.S. Army research Institute of Environmental Medicine. Technical Report T95-12.

Ramsey, J.D. 1995. Task performance in heat: a review. Ergonomics. 38:1, 154-165.

Reardon, M.J., Smythe III, N., Omer, J., Helms, B., Hager, J.D., Freeze, M., and Buchanan, D. 1996. Physiological and Psychological Effects of Thermally Stressful UH-60 Simulator Cockpit Conditions on Aviators Wearing Standard and Encumbered Flight Uniforms. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory; USAARL Report No. 97-06.

Reardon M.J., Smythe III N., Omer J., Helms B., Estrada A., Freeze M., and Hager J.D. 1997. Effects of Heat Stress and an Encumbered Aviator Uniform on Flight Performance in a UH-60 Helicopter Simulator. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory; USAARL Report No. 97-12.

Sawka, M.N., and Wenger, C.B. 1988. Physiological responses to acute exercise-heat stress. Human Performance Physiology and Environmental Extremes (Eds: Pandolf, K.B., Sawka, M.N., and Gonzalez, R.R.). Indianapolis, IN: Benchmark Press, Inc.

Taylor, H. and Orlansky, J. 1993. The effects of wearing protective chemical warfare combat clothing on human performance. Aviation, Space, and Environmental Medicine. 64: A1-A41.

Thornton, R., Brown, G.A., and Higenbottam, C. 1984. The energy expenditure of helicopter pilots. Aviation, Space, and Environmental Medicine. 55: 746-50.

Thornton, R., Caldwell, J.L., Clark, W., Guardiani, F., and Rosario, J. 1992. Effects on physiology and performance of wearing the aviator NBC ensemble while flying the UH-60 helicopter flight simulator in a controlled heat environment. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-36.

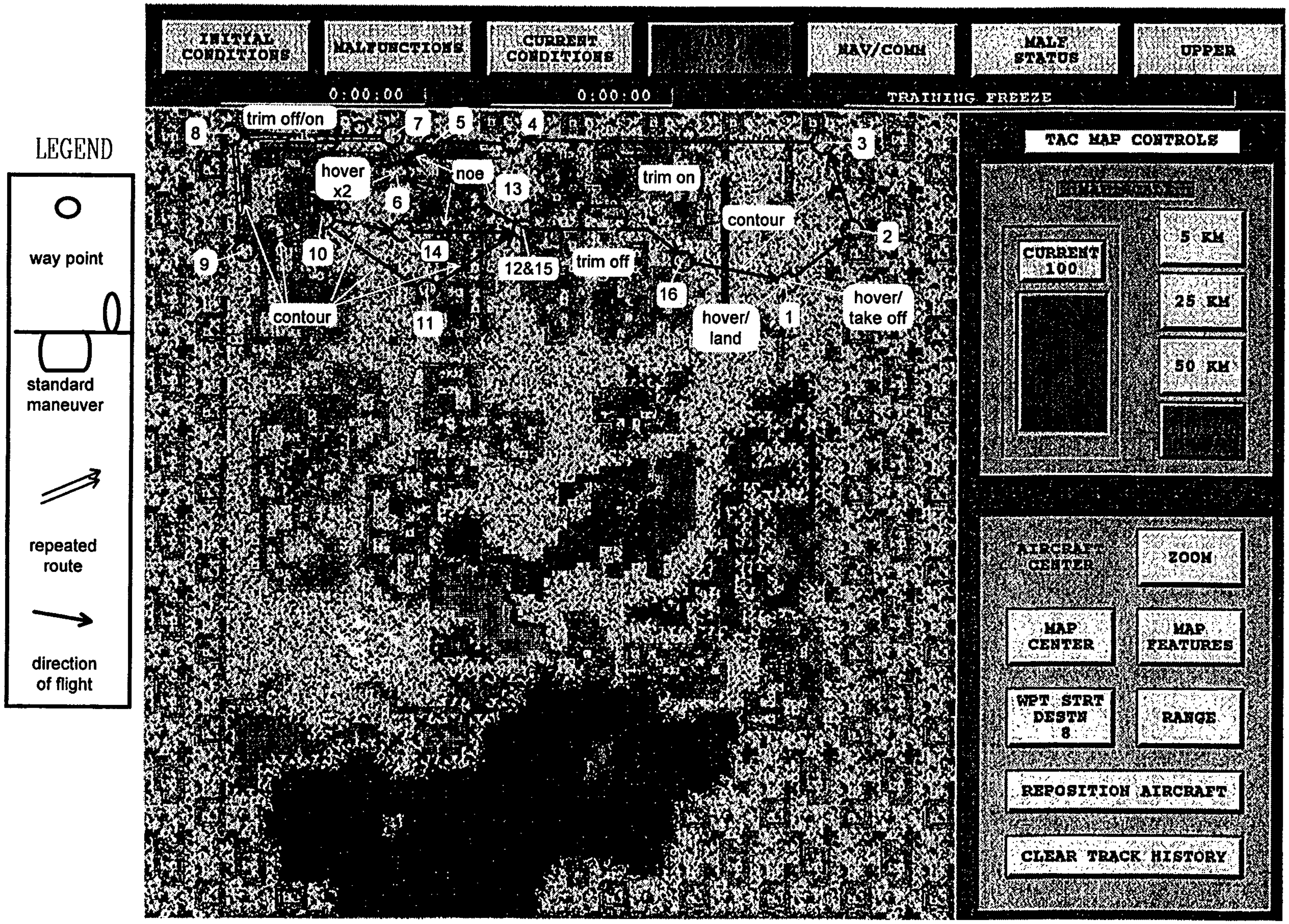
Thornton, R., and Guardiani, F. 1992. The Relationship between environmental conditions and UH-60 cockpit temperature. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-25.

USAAC. 1989. Blackhawk UH-60A Mission profiles and operational mode summaries (MP/OMS). Fort Rucker, AL: U.S. Army Aviation Center.

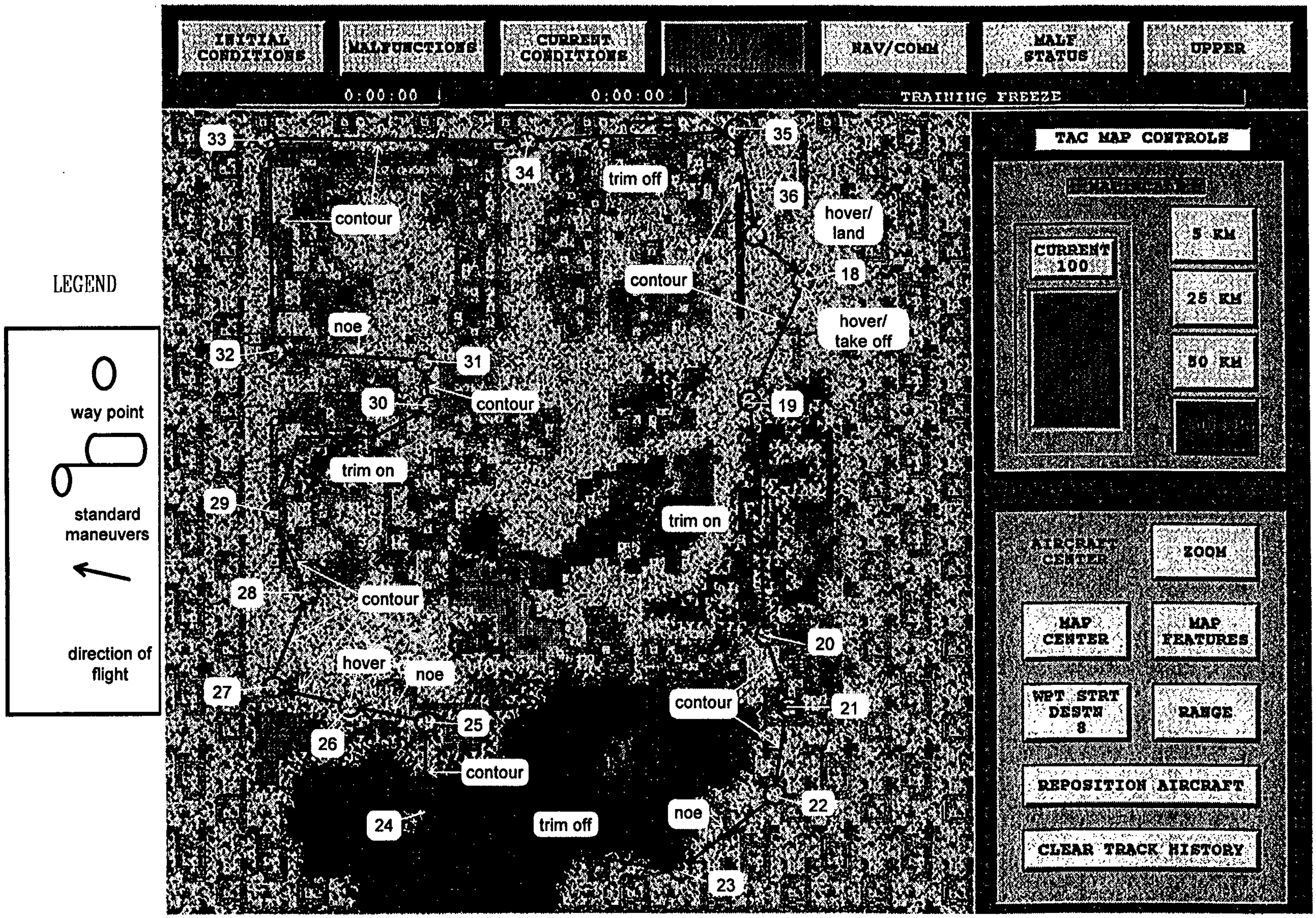
USAARL. 1991. HAWK data acquisition system user's guide. Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Appendix A.

Flight profiles.



First 2-hour sortie: Air assault.



Second 2-hour sortie: MEDEVAC.

Table A-1.
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
1	1	1	Manual start/stop	Hover	1		hdg 360° ,10 ft	Alt, drift, hdg	
2	2	1	Manual start/stop	Hover turn (360°)	1		10 ft	Alt, drift, turn rate	
5	3	1	Manual start	Contour to wp2	3	10.9	var AS, const alt	Alt,grnd track,roll,trim	Admin Mood/Symptom
7.5	4	2	Auto stop/start	Contour to wp3	2.5	10.5	var AS, const alt	Alt, grnd track, roll, trim	
11.5		3	Auto stop	Arrived at wp3 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
12.5	5	3+	Manual start/stop	S&L	1		270°,2k', 120kts	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
14.5	6	3+	Manual start/stop	360° RSRT	2		to hdg 270°,2k',120kts	AS, alt, trim, roll, turn rate	
15.5	7	3+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	
16.5	8	3+	Manual start/stop	L, 180°, ISRT	1		to hdg 090°,2k → 2.5k',120kts	AS, trim, roll, turn rate, ascent rate	
17.5	9	3+	Manual start/stop	S&L	1		090°,2.5k',120kts	AS, alt, trim, roll, hdg	
18.5	10	3+	Manual start/stop	L, 180°, ISRT	1		to hdg 270°,2.5k → 2k',120kts	AS, trim, roll, turn rate, descent rate	
19.5	11	3+	Manual start/stop	S&L	1		270°,2.0k',120kts	AS, alt, trim, roll, hdg	
21.5	12	3+	Manual start/stop	Descend then go to wp4	2		270°,2 → 1k',120kts	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
25	13	4	Auto start	Contour to wp5	3.5	13.4	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
26	14	5	Auto stop/start	NOE to wp6	1	3.3	var AS, var alt<25	Alt, grnd track, roll, trim	

Table A-1 (continued).
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
1	1	1	Manual start/stop	Hover	1		hdg 360° ,10 ft	Alt, drift, hdg	
2	2	1	Manual start/stop	Hover turn (360°)	1		10 ft	Alt, drift, turn rate	
5	3	1	Manual start	Contour to wp2	3	10.9	var AS, const alt	Alt,grnd track,roll,trim	Admin Mood/Symptom
7.5	4	2	Auto stop/start	Contour to wp3	2.5	10.5	var AS, const alt	Alt, grnd track, roll, trim	
11.5		3	Auto stop	Arrived at wp3 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
12.5	5	3+	Manual start/stop	S&L	1		270°,2k', 120kts	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
14.5	6	3+	Manual start/stop	360° RSRT	2		to hdg 270°,2k',120kts	AS, alt, trim, roll, turn rate	
15.5	7	3+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	
16.5	8	3+	Manual start/stop	L, 180°,↑SRT	1		to hdg 090°,2k - 2.5k',120kts	AS, trim, roll, turn rate, ascent rate	
17.5	9	3+	Manual start/stop	S&L	1		090°,2.5k',120kts	AS, alt, trim, roll, hdg	
18.5	10	3+	Manual start/stop	L, 180°,↓SRT	1		to hdg 270°,2.5k - 2k',120kts	AS, trim, roll, turn rate, descent rate	
19.5	11	3+	Manual start/stop	S&L	1		270°,2.0k',120kts	AS, alt, trim, roll, hdg	
21.5	12	3+	Manual start/stop	Descend then go to wp4	2		270°,2 - 1k',120kts	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
25	13	4	Auto start	Contour to wp5	3.5	13.4	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
26	14	5	Auto stop/start	NOE to wp6	1	3.3	var AS, var alt<25	Alt, grnd track, roll, trim	

Table A-1 (continued).
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
		6	Auto stop	Arrived at wp6				None	
27	15	6	Manual start/stop	Hover	1		hdg 360°, 10 ft	Alt, drift, hdg	
28	16	6	Manual start/stop	Hover turn (360°)	1		10 ft	Alt, drift, turn rate	
29.8	17	6	Auto start	Contour to wp7	1.8	5.3	var AS, const alt	Alt,grnd track,roll,trim	Admin Mood/Symptom
33.8		7	Auto stop	Arrived at wp7 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
34.8	18	7+	Manual start/stop Trim off	S&L	1		270°,2k', 120kts	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
36.8	19	7+	Manual start/stop	360° RSRT	2		to hdg 270°,2k',120kts	AS, alt, trim, roll, turn rate	
37.8	20	7+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	
38.8	21	7+	Manual start/stop	L, 180°, ISRT	1		to hdg 090°,2k → 2.5k',120kts	AS, trim, roll, turn rate, ascent rate	
39.8	22	7+	Manual start/stop	S&L	1		090°,2.5k',120kts	AS, alt, trim, roll, hdg	
40.8	23	7+	Manual start/stop	L, 180°, ISRT	1		to hdg 270°,2.5k → 2k',120kts	AS, trim, roll, turn rate, descent rate	
42.8	24	7+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	
43.8	25	7+	Manual start/stop Trim on	Descend then go to wp8	2		270°,2k → 1k',120kts	AS, trim, roll, hdg, descent rate	Administer TLX to Pilot
46.8	26	8	Auto start	Contour to wp9	3	12.5	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
49.8	27	9	Auto stop/start	Contour to wp10	3	11.6	var AS, const alt	Alt, grnd track, roll, trim	

Table A-1 (continued).
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
53.3	28	10	Auto stop/start	Contour to wp11	3.5	13	var AS, const alt	Alt, grnd track, roll, trim	Admin Mood/Symptom
57.8	29	11	Auto start	Contour to wp12	4.5	16	var AS, const alt	Alt, grnd track, roll, trim	
60.3	30	12	Auto stop/start	NOE to wp13	2.5	8.7	var AS, var alt<25	Alt, grnd track, roll, trim	
62.8	31	13	Auto stop/start	Noe to wp6	2.5	8	Vas AS Var Alt <25	Alt,grnd track,roll,trim	
		6	Auto stop	Arrive wp6			hdg 360°, 10 ft	None	
63.8	32	6	Manual start/stop	Hover	1		Hdg 360°,10 ft	Alt,drift,Hdg	
64.8	33	6	Manual start/stop	Hover turn (360°)	1		10 ft	Alt, drift, turn rate	
66.6	34	6	Manual start	Contour to wp7	1.8	5.3	var AS, const alt	Alt,grnd track,roll, trim	
70.6		7	Auto stop	Arrived at wp7 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
71.6	35	7+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
73.6	36	7+	Manual start/stop	360° RSRT	2		270°,2k',120kts	AS, alt, trim, roll, turn rate	
74.6	37	7+	Manual start/stop	S&L	1		270°,2k',120kts	AS, alt, trim, roll, hdg	
75.6	38	7+	Manual start/stop	L, 180°,1SRT	1		to hdg 090°,2k - 2.5k',120kts	AS, trim, roll, turn rate, ascent rate	
76.6	39	7+	Manual start/stop	S&L	1		090°,2.5k',120kts	AS, alt, trim, roll, hdg	
77.6	40	7+	Manual start/stop	L, 180°,1SRT	1		to hdg 270°,2.5k - 2k',120kts	AS, trim, roll, turn rate, descent rate	
78.6	41	7+	Manual start/stop	S&L	1		270°,2.0k',120kts	AS, alt, trim, roll, hdg	

Table A-1 (continued).
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
80.6	42	7+	Manual start/stop	Descend then go to wp8	2		270°,2 - 1k',120kts	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
83.6	43	8	Auto start	Contour to wp9	3	12.5	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
86.6	44	9	Auto stop	Contour to wp10	3	11.6	var AS, const alt	Alt, grnd track, roll, trim	Admin Mood/Symptom
89.6	45	10		Contour to wp14	3	12.2	var AS, const alt	Alt, grnd track, roll, trim	
91.6	46	14	Auto start	NOE to wp15	2	10	var AS, var alt<25	Alt, grnd track, roll, trim	
95.6		15	Auto stop	Arrive at wp15 Ascend to 2K'	4			None	Cue Co-pilot to prepare for MATB
96.6	47	15+	Manual start/stop Trim off	S&L	1		090°,2k',120kts	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
98.6	48	15+	Manual start/stop	360° RSRT	2		090°,2k',120kts	AS, alt, trim, roll, turn rate	
99.6	49	15+	Manual start/stop	S&L	1		090°,2k',120kts	AS, alt, trim, roll, hdg	
100.6	50	15+	Manual start/stop	L, 180°, ISRT	1		to hdg 270°,2k - 2.5k',120kts	AS, trim, roll, turn rate, ascent rate	
101.6	51	15+	Manual start/stop	S&L	1		270°,2.5k',120kts	AS, alt, trim, roll, hdg	
102.6	52	15+	Manual start/stop	L, 180°, ISRT	1		to hdg 090°,2.5k - 2k',120kts	AS, trim, roll, turn rate, descent rate	
103.6	53	15+	Manual start/stop	S&L	1		090°,2.0k', 120kts	AS, alt, trim, roll, hdg	
105.6	54	15+	Manual start/stop Trim on	Descend then go to wp16	2		090°,2 - 1k', 120kts	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
108.6	55	16	Auto start	Contour to wp1	3	12.4	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB

Table A-1 (continued).
Air assault scenario.

Time	Man	WP	Action	Maneuver	Min	Km	Standards	Variables to score	Notes
		1	Auto stop	Arrived at wp1				None	
109.6	56	1	Manual start/stop	Hover	1		hdg 360° ,10 ft	Alt, drift, hdg	
110.6	57	1	Manual start/stop	Hover turn (360°)	1		10 ft	Alt, drift, turn rate	Admin Mood/Symptom At end of maneuver
				Total	110.6				

Table A-2.
MEDEVAC scenario.

Time	Man	WP	Action	Maneuver	Mins	Km	Standards	Variables to score	Notes
1	1	18	Manual start/stop	Hover	1		10 ft alt, 360°hdg	Alt, drift, hdg	
2	2	18	Manual start/stop	Hover turn (360°)	1			Alt, drift, turn rate	
7.3	3	19	Manual start	Contour to wp19	5.3	20	var AS, const alt	Alt, grnd track, roll, trim	Admin Mood/Symptoms
11.3		19	Auto stop	Reached wp19 Ascend to 2k'	4				Cue Co-pilot to prepare for MATB
12.3	4	19+	Manual start/stop	S&L	1		120kts,2k',180°	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
14.3	5	19+	Manual start/stop	RSRT	2		360°	AS, alt, trim, roll, turn rate	
15.3	6	19+	Manual start/stop	S&L	1		120kts,2k',180°	AS, alt, trim, roll, hdg	
16.3	7	19+	Manual start/stop	L, 180°,↑SRT	1		2.0k→2.5k'	AS, trim, roll, turn rate, ascent rate	
17.3	8	19+	Manual start/stop	S&L	1		120kts,2.5k',360°	AS, alt, trim, roll, hdg	
18.3	9	19+	Manual start/stop	L, 180°,↓SRT	1		2.5k →2k'	AS, trim, roll, turn rate, descent rate	
19.3	10	19+	Manual start/stop	S&L	1		120kts,2.0k',180°	AS, alt, trim, roll, hdg	
21.3	11	19+	Manual start/stop	Descend then go to wp20	2		120kts,2.0 → 1.0k',180°	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
23.3	12	20	Auto start	Contour to wp21	2	8.4	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
26.3	13	21	Auto stop/start	Contour to wp22	3	11.8	var AS, var alt<25	Alt, grnd track, roll, trim	Admin Mood/Symptoms
30.3	14	22	Auto stop/start	NOE to wp23	4	14.8	var AS, var alt<25	Alt, grnd track, roll, trim	
34.3		23	Auto stop	Arrive at wp23 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
35.3	15	23+	Manual start/stop Trim off	S&L	1		120kts,2k',270°	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB

Table A-2 (continued).
MEDEVAC scenario.

Time	Man	WP	Action	Maneuver	Mins	Km	Standards	Variables to score	Notes
37.3	16	23+	Manual start/stop	RSRT	2		360°	AS, alt, trim, roll, turn rate	
38.3	17	23+	Manual start/stop	S&L	1		120kts,2k',270°	AS, alt, trim, roll, hdg	
39.3	18	23+	Manual start/stop	L, 180°, ↑SRT	1		2.0k → 2.5k'	AS, trim, roll, turn rate, ascent rate	
40.3	19	23+	Manual start/stop	S&L	1		120kts,2.5k',090°	AS, alt, trim, roll, hdg	
41.3	20	23+	Manual start/stop	L, 180°,↓SRT	1		2.5k → 2k'	AS, trim, roll, turn rate, descent rate	
42.3	21	23+	Manual start/stop	S&L	1		120kts,2.0k',270°	AS, alt, trim, roll, hdg	
44.3	22	23+	Manual start/stop Trim on	Descend then go to wp24	2		120kts,2.0k',→ 1.0k',270°	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
47.3	23	24	Auto start	Contour to wp25	3	10.6	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
49.3	24	25	Auto stop/start	NOE to wp26	2	10	var AS, var alt<25'	Alt, grnd track, roll, trim	
		26	Auto stop	Arrived at wp26				None	
50.3	25	26	Manual start/stop	Hover	1		10 ft alt, 360° hdg	Alt, drift, hdg	
51.3	26	26	Manual start/stop	Hover turn (360°)	1		10 ft alt	Alt, drift, turn rate	
53.8	27	26	Manual start	Contour to wp27	2.5	9	var AS, const alt	Alt, grnd track, roll, trim	Admin Moods/Symptoms
56.8	28	27	Auto stop/start	Contour to wp28	3	12.5	var AS, const alt	Alt, grnd track, roll, trim	
60.3	29	28		Contour to wp 29	3.5	13.5		Alt, grnd track, roll, trim	
64.3		29	Auto stop	Arrived at wp29 Ascend to 2k'	4			None	Cue Co-pilot to prepare for MATB
65.3	30	29+	Manual start/stop	S&L	1		120kts,2k',090°	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
67.3	31	29+	Manual start/stop	RSRT	2		360°	AS, alt, trim, roll, turn rate	

Table A-2 (continued).
MEDEVAC scenario.

Time	Man	WP	Action	Maneuver	Mins	Km	Standards	Variables to score	Notes
68.3	32	29+	Manual start/stop	S&L	1		120kts,2k',090°	AS, alt, trim, roll, hdg	
69.3	33	29+	Manual start/stop	L, 180°, ↑SRT	1		2.0k →2.5k'	AS, trim, roll, turn rate, ascent rate	
70.3	34	29+	Manual start/stop	S&L	1		120kts,2.5k',270°	AS, alt, trim, roll, hdg	
71.3	35	29+	Manual start/stop	L, 180°, ↓SRT	1		2.5k → 2k'	AS, trim, roll, turn rate, descent rate	
72.3	36	29+	Manual start/stop	S&L	1		120kts,2.0k',090°	AS, alt, trim, roll, hdg	
74.3	37	29+	Manual start/stop	Descend then go to wp 30	2		120kts,2.0→ 1.0K',090°	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
75.3	38	30	Auto start	Contour to wp31	1	4	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
79.8	39	31	Auto stop/start	NOE to wp32	4.5	16.6	var AS, var alt<25	Alt, grnd track, roll, trim	
87.3	40	32	Auto stop/start	Contour to wp33	7.5	28.2	var AS, const alt	Alt,grnd track,roll,trim	Admin Mood/Symptoms
96.3	41	33	Auto stop/start	Contour to wp34	9	33.1	var AS, const alt	Alt,grnd track,roll ,trim	
100.3		34	Auto stop	Arrive wp 34 Ascend to 2k'	4		var AS, const alt	Alt, grnd track, roll, trim	Cue Co-pilot to for MATB prepare
101.3	42	34+	Manual start/stop Trim off	S&L	1		120kts,2k',090°	AS, alt, trim, roll, hdg	Cue Co-pilot to begin MATB
103.3	43	34+	Manual start/stop	RSRT	2		360°	AS, alt, trim, roll, turn rate	
104.3	44	34+	Manual start/stop	S&L	1		120kts,2k',90°	AS, alt, trim, roll, hdg	
105.3	45	34+	Manual start/stop	L, 180°,↑SRT	1		2.0k → 2.5k'	AS, trim, roll, turn rate, ascent rate	
106.3	46	34+	Manual start/stop	S&L	1		120kts,2.5k',270°	AS, alt, trim, roll, hdg	
107.3	47	34+	Manual start/stop	L, 180°, ↓SRT	1		2.5k→ 2k'	AS, trim, roll, turn rate, descent rate	
108.3	48	34+	Manual start/stop	S&L	1		120kts,2.0k',090°	AS, alt, trim, roll, hdg	

Table A-2 (continued).
MEDEVAC scenario.

Time	Man	WP	Action	Maneuver	Mins	Km	Standards	Variables to score	Notes
109.3	49	34+	Manual start/stop Trim on	Descend then go to wp35	1		120kts,2.0→ 1.0k',090°	AS, trim, roll, hdg, descent rate	Administer TLX to pilot
112.3	50	35	Auto start	Contour to wp36	3	12.5	var AS, const alt	Alt, grnd track, roll, trim	Admin TLX to Co-pilot at end of MATB
116.3	51	36	Auto stop/start	NOE to wp18	4	6.5	var AS, var alt<25	Alt, grnd track, roll, trim	
		18	Auto stop	Arrived at wp18				None	
117.3	52	18	Manual start/stop	Hover	1		10 ft alt, 360 hdg	Alt, drift, hdg	
118.3	53	18	Manual start/stop	Hover turn (360°)	1		10 ft alt	Alt, drift, turn rate	Admin Mood/Symptoms when maneuver complete
				Total	118.3				

Appendix B.

Test session run identifiers.

Simulator Test Session Run Identifier

revised(5-12-97)

Fields 1-2: The two digit number of the test subject in the right hand pilot seat

Fields 3-4: The two digit number for the day ranging from 01-21

Field 5: The one digit number for the run

Field 6: The one letter designation for the temperature
- C= moderate temperature
- H= hot temperature
- T= training

Field 7: The one letter designation for NAVY
- N= NAVY

Field 8: The one letter designation for the profile
- A= air assault
- M= medevac

Field 9-10: The two digit number of the test subject in the left hand pilot seat
- 99 = no one in this seat

Time Stamps:
- 0 = pilot is flying
- 1= copilot is flying
- 2= pilot mask off
- 3= pilot mask on
- 4= copilot mask off
- 5= copilot mask on
- 9= crash

(Effective 04-24-96)

The ten-place alphanumeric simulator test session run identifier was entered into the VAX by the simulator operator for physiological and flight performance data collection. The run identifier was associated with the Hawk marker files and was used to query and generate segment files for data analysis. Fields 1 and 2 represent the test subject in the pilot seat. Fields 3 and 4 represent the day of testing or training. Field 5 is the run number. Field 6 is the one letter designation for the temperature condition. Field 7 is the one letter representation of the uniform condition. Field 8 is the one letter designation for the flight scenario. Fields 9 and 10 represent the test subject in the co-pilot's seat. In addition to the run identifier, time stamps were also entered by the simulator operator to indicate when controls were changed out during nonstandard maneuvers, when the pilots removed or replaced their mask, and when crashes occurred.

Appendix C.

Questionnaires.

TASK LOAD INDEX QUESTIONNAIRE

v 6/6/97

Today's Date:__________ Test Subject No. ______

❑ Instructions:
1. Administer the series of questions as indicated by the flight profiles.
2. Alert test subject "TEST SUBJECT NAME, TLX QUESTIONAIRE".
3. Wait for acknowledgement, then go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

	QUESTION	SCALE		RATINGS*							
	On a scale of 0 to 10 please assess your experience with respect to the (set of standard maneuvers/MATB) of the following conditions:		Timer time								
1	mental demand	(0 =low	10=high)								
2	physical demand	(0 =low	10=high)								
3	temporal demand	(0=low	10=high)								
4	performance	(0=good	10=poor)								
5	effort	(0=low	10=high)								
6	frustration	(0=low	10=high)								
			Technicians initials--								

*data entered on template in correct TLX scale

SEAWAR MOOD AND SYMPTOMS QUESTIONNAIRE
v 5/12/97

Today's Date:__________ Test Subject No. ____

❑ Instructions:
1. Administer the series of questions at the following times: Just prior to simulated pre-flight, 15 minutes into simulated pre-flight and at times indicated in flight profile.
2. Alert the test subject with the following :"Test subjects name, Mood and symptoms questionnaire "
3. Go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

	QUESTION	SCALE	(Treadmill)	RATINGS AT 30 MIN INTERVALS										
	On a scale of 0 to 10 with respect to the past 5-10 min please rate your sensation of:	Timer Time (Hrs:mins)--->												
1	headache	(0 = none 10 = very severe)												
2	nausea	(0 = none 10 = about to vomit)												
3	stress	(0 = none 10 = very severe, can't take it)												
4	anger	(0 = none 10 = extremely)												
5	depression	(0 = none 10 = extremely)												
6	energy	(0 = none 10 = a lot)												
7	heat stress	(0 = none 10 = unbearable)												
8	thirst	(0 = none 10 = severe)												
9	workload	(0 = very light 10 = overwhelming)												
10	boredom	(0 = none 10 = totally boring)												
11	dizziness	(0 = none 10 = very severe)												
12	visual difficulty	(0 = none 10 = can hardly see)												
13	hot spots location: (0 = none 10 = a lot)	a) head b) chest c) back d) buttocks e) arm f) leg g) other												
		Technician initials --->												

esq1.frm

NAME ______________________ DATE ____________

SEX: Male Ⓜ Female Ⓕ

IDENTIFICATION

Below is a list of words that describe feelings people have. Please read each one carefully. Then fill in ONE circle under the answer to the right which best describes HOW YOU ARE FEELING RIGHT NOW.

The numbers refer to these phrases.

0 = Not at all
1 = A little
2 = Moderately
3 = Quite a bit
4 = Extremely

Col © O.P. ⓞ

	NOT AT ALL	A LITTLE	MODERATELY	QUITE A BIT	EXTREMELY
1. Friendly	0	1	2	3	4
2. Tense	0	1	2	3	4
3. Angry	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Unhappy	0	1	2	3	4
6. Clear-headed	0	1	2	3	4
7. Lively	0	1	2	3	4
8. Confused	0	1	2	3	4
9. Sorry for things done	0	1	2	3	4
10. Shaky	0	1	2	3	4
11. Listless	0	1	2	3	4
12. Peeved	0	1	2	3	4
13. Considerate	0	1	2	3	4
14. Sad	0	1	2	3	4
15. Active	0	1	2	3	4
16. On edge	0	1	2	3	4
17. Grouchy	0	1	2	3	4
18. Blue	0	1	2	3	4
19. Energetic	0	1	2	3	4
20. Panicky	0	1	2	3	4
21. Hopeless	0	1	2	3	4
22. Relaxed	0	1	2	3	4
23. Unworthy	0	1	2	3	4
24. Spiteful	0	1	2	3	4
25. Sympathetic	0	1	2	3	4
26. Uneasy	0	1	2	3	4
27. Restless	0	1	2	3	4
28. Unable to concentrate	0	1	2	3	4
29. Fatigued	0	1	2	3	4
30. Helpful	0	1	2	3	4
31. Annoyed	0	1	2	3	4
32. Discouraged	0	1	2	3	4
33. Resentful	0	1	2	3	4
34. Nervous	0	1	2	3	4
35. Lonely	0	1	2	3	4
36. Miserable	0	1	2	3	4
37. Muddled	0	1	2	3	4
38. Cheerful	0	1	2	3	4
39. Bitter	0	1	2	3	4
40. Exhausted	0	1	2	3	4
41. Anxious	0	1	2	3	4
42. Ready to fight	0	1	2	3	4
43. Good natured	0	1	2	3	4
44. Gloomy	0	1	2	3	4
45. Desperate	0	1	2	3	4
46. Sluggish	0	1	2	3	4
47. Rebellious	0	1	2	3	4
48. Helpless	0	1	2	3	4
49. Weary	0	1	2	3	4
50. Bewildered	0	1	2	3	4
51. Alert	0	1	2	3	4
52. Deceived	0	1	2	3	4
53. Furious	0	1	2	3	4
54. Efficient	0	1	2	3	4
55. Trusting	0	1	2	3	4
56. Full of pep	0	1	2	3	4
57. Bad-tempered	0	1	2	3	4
58. Worthless	0	1	2	3	4
59. Forgetful	0	1	2	3	4
60. Carefree	0	1	2	3	4
61. Terrified	0	1	2	3	4
62. Guilty	0	1	2	3	4
63. Vigorous	0	1	2	3	4
64. Uncertain about things	0	1	2	3	4
65. Bushed	0	1	2	3	4

MAKE SURE YOU HAVE ANSWERED EVERY ITEM.

POM 021

Appendix D.

Data collection forms.

SEAWAR TS MONITORING & BACKUP DATA COLLECTION FORM

Today's Date: ____________ Test Subject No.: _____

Uniform: ① ABDU ② Sea Warrior Activity: 1 training/acclimatizing 2 testing

Environmental condition: ① moderate (70°F, 50%rh) ② hot (100°F, 50%rh)

Estimated max heart rate: _____ 90% max: _____ 80% max: ____

Entry #	Clock time (hrs:min)	Timer time (hrs:min)	Cabin temp (°F)	RH %	Heart rate	Core temp (°C)	Test Subject Activity	Comments

Enter heart rate & core temp every 10 mins. Limits: core temp =102.5F (39.2C), heart rate not more than 90% of predicted max.

SEAWAR TS WEIGHT & FLUID BALANCE WORKSHEET (rev.06-13-97)

Today's Date: ___________ Test Subject No.: _____
Uniform: ① standard flight ② Sea Warrior
Activity: ① training/acclimatizing ② testing
Environmental condition: ① moderate (70°F, 50%rh) ② hot (100°F, 50%rh)

→PRETEST:	→POSTTEST:
❑ Nude weight _______ kg ❑ Clothed & instrumented weight: _______ kg	❑ Clothed & instrumented weight: _______ kg ❑ Nude weight _______ kg

→ URINE OUTPUT: (Formula Number 7)

Formula Number	Time of urination	Empty Specimen Container Wgt (kg)	Full Specimen Container Wgt (kg)	Full Wgt - Empty Wgt (kg)
10	After pre-clothed			
	After post-nude			

→ FLUID INTAKE: (Formula Number 5)

Formula Number	Time of intake	Fluid Container Label Name or #	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)
	After pre-nude				
8	After pre-clothed				
8					
8					
	After post-clothed				

→ FOOD INTAKE: (Formula Number 6 and 9)

Type of Food	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)

SIMULATOR FLIGHT INCIDENTS

Today's Date: ____________ Cockpit Temp: ______°F Humidity: _____ Uniform: ___________

	TS# __	TS# __	TS# __	TS# __	TS# __	TS# __
	Time into Mission & CoreTemp	Time into Mission & CoreTemp	Time into Mission & CoreTemp	Time into Mission & CoreTemp	Time into Mission & CoreTemp	Time into Mission & CoreTemp
TYPE OF INCIDENT	______Hrs ______°C ______min	______Hrs ______°C ______min	______Hrs ______°C ______min	______Hrs ______°C ______min	______Hrs ______°C ______min	______Hrs ______°C ______min
Crash						
during hover	❑	❑	❑	❑	❑	❑
attempting to land	❑	❑	❑	❑	❑	❑
flew into terrain	❑	❑	❑	❑	❑	❑
loss of control at alt	❑	❑	❑	❑	❑	❑
other	❑	❑	❑	❑	❑	❑
explanation						
Simulator sickness						
needed to transfer control	❑	❑	❑	❑	❑	❑
had to exit simulator	❑	❑	❑	❑	❑	❑
caused a crash	❑	❑	❑	❑	❑	❑
other	❑	❑	❑	❑	❑	❑
explanation						
Simulator malfunction						
electrical problem	❑	❑	❑	❑	❑	❑
mechanical "	❑	❑	❑	❑	❑	❑
computer "	❑	❑	❑	❑	❑	❑
navigational "	❑	❑	❑	❑	❑	❑
other	❑	❑	❑	❑	❑	❑
time lost	____ mins	____ mins	____ mins	____ mins	____ mins	____ mins
explanation						
Other						
explanation	❑	❑	❑	❑	❑	❑

Appendix E.

Checklists and procedures.

Sensor application procedure

1. Apply Benzion to area of chest where first sensor is to be placed.
2. Make a loop in sensor lead and tape down approx. 2" from where sensor is to be placed.
3. While holding sensor in place with a cotton swab,pour a small amount of Colloidon on and around the sensor.
4. Using the air pump, air dry the Colloidon.When dry tape down the sensor.
5. Repeat these proceedures for each sensor,placing the 2nd sensor on the upper arm mid way between the elbow and the shoulder (thread sensor up under T-shirt and out through sleeve),the 3rd on the outside of the thigh mid way between knee and hip,the 4th on the outside of the lower leg on the calf muscle.
6. Place the EKG sensors on the chest ,one on each side of the upper chest and one on the right side of the chest just over the last rib.
7. Attach the leads to the sensors,right arm to the right upper chest,left arm to the left upper chest and right leg tothe right lower chest.
8. Assist the test subject dressing,assuring no leads pull lose.
9. Tape excess wires together leaving ends free to allow for disconnect and reconnect.
10. After placing Squirrel in the carrying case connect leads to the Squirrel.

Test subject checklist.

1. TEST SUBJECT EQUIPMENT	**2. VITALS CHECKLIST**	**3. PRETEST HOOK-UP**
COMPLETE FLIGHT SUIT	INITIALS	SET-UP EQUIPMENT(squirrel,cables,cortemp,"R" wave counter)
NBC BOOTS	COMPLETE TEST SUBJECT DATA COLLECTION FORMS	TEST SUBJECT EMPTY BLADDER AND NOTE TIME
NBC OVER GARMENT	BLOOD PRESSURE (Supine & Standing)	TEST SUBJECT INSERT PROBE
WATER WINGS (snug under arm pits)	RESPIRATION	TEST SUBJECT NUDE WEIGHT
CHICKEN PLATE	PULSE/HEART RATE	ADJUST "R" WAVE CABLES
SARVIP (with O2 bottle,survival knife,pistol,full pouches)	ORIENTATION	APPLY SENSORS
RAFT	ATAXIA	CHECK SQUIRREL READINGS
M431A CB MASK	ORAL TEMPERATURE	AID TEST SUBJECT DRESSING
FLIGHT HELMET	CHECK TEST SUBJECT EQUIPMENT	BEGIN DATA COLLECTION (squirrels & Questionnaire)
		ESCORT TEST SUBJECT TO ENVIRONMENTAL CHAMBER
4. SIMULATOR PREP	**5. ENVIRONMENTAL CHAMBER**	**6. SIMULATOR**
CONNECT BLUE HAWK CABLE	SET UP TREADMILL (0 degrees incline,20 minute interval,3.0mph)	DISCONNECT SQUIRREL CABLE FROM TEST SUBJECT
TURN ON DATA ACQUISITION MONITOR/KEYBOARD	COLLECT DATA AT PRESCRIBED INTERVAL(heart rate,core temp.,relative humidity,chamber temp.)	CONNECT TEST SUBJECT SENSOR CABLE TO VAX
TURN ON CAMERA BOX	OBSERVE TEST SUBJECT FOR HEAT STRESS REACTION	CHECK PATCH CABLE POLARITY
TURN ON T.V. MONITOR	ASK MEDICAL QUESTIONS AT PRESCRIBED INTERVALS	CHECK COMMUNICATIONS HOOK-UP WITH TEST SUBJECT & TECH
TURN ON CPU		INSURE CAMERAS SET TO PROPER ORIENTATION
LOAD MATB VOICE FILES		PT MONITER
LOAD MATB		INSURE TECH IS STRAPPED IN
TEST SOUND		COLLECT DATA FROM D.A.B. AT PRESCRIBED INTERVALS
CHECK SCRIPT		ADMINISTER QUESTIONAIRES (MOODSYS,TLX,) AT PRESCRIBED INTERVALS
CHECK GAIN		CUE START OF MATB AT PRESCRIBED INTERVALS
		OBSERVE TEST SUBJECT
		UNHOOK TEST SUBJECT
7. SIMULATOR POST FLIGHT	**8. RECOVERY ROOM**	**9. POST-TEST CHECKLIST**
PLACE DISKETTE IN "A" DRIVE	CHECK LIFPAK	REMOVE SENSORS
DOWNLOAD MATB DATA FILES	OBTAIN POST TEST WEIGHT CLOTHED	OBTAIN POST TEST CATECHOLAMINE URINE SAMPLE
REMOVE MATB KEYBOARD/MONTIOR	OBTAIN POST TEST CATECHOLAMINE URINE SAMPLE	OBTAIN POST TEST NUDE WEIGHT
TURN OFF T.V.	REHYDRATE TEST SUBJECT	CLEAN PROBES &SENSORS
TURN OFF CAMERA BOX	ADMINSTER POMS	RESTOCK BATH ROOM CART
MAKE SURE ALL MATERIALS ARE OUT OF SIMULATOR		STORE PROBES IN DISINFECTANT
		CLEAN UP & PREPARE LAB FOR NEXT DAY

Appendix F.

Manufacturers and product information.

Digital Equipment Corporation 110 Spit Brook Road Nashu, NH 03062-2698	VAX 11/780 Computer
Microsoft Corporation P.O. Box 72368 Roselle, Illinois 66172-9900	Microsoft Office Professional
NASA Langley Research Center Hampton, Virginia 23665-5225	Multi-attribute task battery
SPSS, Inc. 444 North Michigan Avenue Chicago, Illinois 60611	SPSS statistical software
Statsoft 2325 East 13th Street Tulsa, Oklahoma 74104	Statistica software
Vermont Medical, Inc. Industrial Park Bellows Falls, Vermont 05101-3122	ECG pads
Yellow Springs Instrument Company P.O. Box 279 Yellow Springs, Ohio 45387	Rectal and skin thermistors